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Generative Artificial Intelligence Studies and Research Trends in Science Education[1]

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Abstract: This study aims to provide a comprehensive analysis of the application areas and research trends of generative artificial intelligence (GAI) in science education. The objective is to explore how GAI is utilized to enhance educational processes such as knowledge exploration, material production, and student assessment, while also addressing teachers' perceptions and challenges related to its use. A literature review was conducted on 27 articles published between 2021 and 2024 in the Web of Science database. These articles were analyzed descriptively based on their research topics, GAI methods/tools utilized, research contexts, and suggested areas for future studies. The study found that GAI is employed in STEM education to enhance student achievement, support scientific process skills, and aid in understanding complex concepts. Teachers' perceptions of GAI are influenced by knowledge gaps, ethical concerns, and misunderstandings. While educators recognize the benefits of GAI, such as improving instructional practices and engaging students, they also express concerns about information accuracy, risks of plagiarism, and ethical responsibilities. The findings emphasize the importance of teacher guidance in using GAI tools like ChatGPT effectively in educational settings. Additionally, the study highlights the need for adapting GAI tools to instructional contexts to ensure reliable and ethical classroom applications. Future research is recommended to develop strategies for more dependable and ethical use of GAI, as well as to provide comprehensive guidance for educators to maximize its potential in science education.

Keywords: Generative artificial intelligence, science education, ChatGPT, artificial intelligence applications in education.

Introduction

The rapid advancement of technological developments and the integration of artificial intelligence into these technologies have further accelerated this evolution. After the Covid-19 pandemic, concepts like high-speed internet, artificial intelligence, big data, and cloud services quickly entered our lives between 2020 and 2023 (Nabiyev & Erümit, 2024). Today, artificial intelligence (AI) and its subfields, such as machine learning and deep learning, have permeated almost every aspect of our lives. Artificial intelligence is a scientific field that allows machines, especially computer systems, to mimic and apply various features of human intelligence. This technology simulates human behaviors in skills such as learning, reasoning, problem-solving, perception, and language processing. Through algorithms, data structures, and mathematical models, AI enables machines to learn from datasets, quickly adapt to new situations, and make complex decisions (Avcı, 2024). According to Miller (2023), artificial intelligence is the capacity of a machine or computer to carry out operations that normally call for human intelligence, stating that AI involves training machines to "think" like humans. In other words, artificial intelligence refers to technologies created with fully artificial tools capable of simulating cognitive processes such as thinking, decision-making, and learning like a

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human (Nabiyev & Erümit, 2024). Furthermore, AI can be defined as the development of computer systems programmed to model and mimic human behaviors (Nabiyev & Erümit, 2024).

Generative artificial intelligence (GAI), a subfield of AI, specifically focuses on producing new content, data, or ideas by learning from existing information. For example, GAI can create entirely new human faces that have never existed by analyzing real human faces. This capability aligns closely with the generative learning theory, which posits that individuals actively construct their own understanding by integrating new knowledge with their existing knowledge and experiences (Pflieger et al., 2024). At the core of this theory is the idea that learning is an active, sense-making process involving cognitive activities such as organizing, integrating, and elaborating on new information (Fiorella, 2023). Similarly, GAI synthesizes and organizes data to generate novel outputs, reflecting these cognitive processes. Furthermore, the theory emphasizes motivation and attention as critical factors for meaningful learning, which can be paralleled to GAI's requirement for targeted datasets and algorithmic focus to produce meaningful and relevant results (Pflieger et al., 2024). By linking new data to existing patterns and creating new mental representations, GAI serves as a technological extension of the generative learning framework, demonstrating how active knowledge construction can lead to innovative and transferable outputs (Fiorella, 2023).

With this creative aspect, GAI stands out from other AI applications, emphasizing its capacity for generating original data (Avcı, 2024). In addition, artificial intelligence has a wide range of applications in areas such as problem-solving, gaming and knowledge modeling, automated theorem proving, expert systems, natural language processing, audio processing, pattern recognition, and robotics (Nabiyev & Erümit, 2024). Finally, AI is also defined as an effort to emulate human behaviors, reasoning, inference, and even emotional characteristics, such as feeling sadness or joy, within machines (Korucu & Biçer, 2024). The integration of AI into daily life has accelerated with the development of deep learning and big data processing techniques, encompassing stages of learning and interpreting knowledge (Arık & Seferoğlu, 2024).

Generative Artificial Intelligence and Educational Applications

The underlying factors driving the active use of artificial intelligence across all fields can be listed as efficiency and speed, error reduction, decision-making, personalization, innovation, creativity, accessibility, and solving global problems (Avcı, 2024). The productivity that these capabilities will bring to educational environments will impact classrooms, just as AI has become integral to our daily lives, as it saves time for teachers and supports educational processes (Miller, 2023). Korucu and Biçer (2024) summarize examples of the use of generative AI in educational settings and the specific AI techniques utilized in these applications in Table 1.

Upon examining Table 1, it is evident that various techniques offer diverse applications for both teachers and students. For instance, applications that predict student outcomes, a fundamental aspect of data mining, can assist in planning students' development within the educational process. The active use of such applications by teachers and students will enable them to create different career opportunities and benefit from the advantages that technology provides. For example, AI acting as an assistant for teachers will allow them to save significant time and use their knowledge and skills in various fields.

Science Education and Generative Artificial Intelligence

Interest in artificial intelligence applications within science classrooms is growing. Tools for scientific knowledge acquisition, scientific inquiry, and generative AI (e.g., ChatGPT, Sora, Copilot) are increasingly used across various educational settings (Cheung et al., 2024). The use of generative AI tools in science education can diversify learning environments, provide students with new learning opportunities, and reduce teachers' workloads, thus offering significant contributions.

In generating learning materials, generative AI technology can make abstract science concepts more tangible in ways that go beyond traditional virtual reality (VR) or simulation technologies. For instance, in environmental science classes, while VR can provide pre-designed experiences of ecosystems, GAI can dynamically generate unique virtual organisms or ecosystems tailored to students' specific questions or learning needs. Similarly, in chemistry classes, GAI can create novel

molecular structures or configurations based on real-time data or student inputs, allowing for a deeper and personalized understanding of complex scientific phenomena. Unlike traditional simulations, which operate within predefined parameters, GAI's ability to generate customized and adaptive content enhances its potential as a transformative tool in education.

Table 1.
Generative Artificial Intelligence Techniques and Their Applications in Education

Generative AI Technique	Educational Applications and Examples
Machine Learning	- Predicting and assessing student success
	- Recommending and creating personalized lesson content
	- Providing instant feedback
	- Offering technical support
	- Recognizing faces, voices, speech, and fingerprints
	- Facilitating multilingual learning through natural language processing (NLP)
	- Evaluating exams with optical character recognition
Data Mining	- Identifying relationships (e.g., between study time and grades)
	- Predicting student interests, needs, and abilities
	- Predicting student performance
	- Estimating attendance in classes or school
	- Forecasting teacher performance
Artificial Neural Networks	- Translation between languages
	- Translating text or speech
Natural Language Processing (NLP)	- Speech recognition and automated responses
	- Answering questions
	- Conducting sentiment analysis
	- Summarizing articles
	- Correcting spelling errors
Image Processing	- Recognizing faces and fingerprints
	- Translating text in images
Expert Systems	- Determining learning strategies
	- Predicting success
	- Selecting learning models
	- Teaching foreign languages
	- Assessing exams
	- Providing feedback

Customized educational content, visuals, animations, exercises, or tests can be produced by focusing on students' individual differences. Another application of generative AI is the creation of interactive learning environments. Interactive AI applications, such as ChatGPT, can provide virtual tutors, creating environments where students' research questions are answered or topics are explained according to their readiness levels.

Generative AI can support students in educational activities by fostering collaboration, enhancing creativity, and encouraging deeper exploration of scientific concepts, as evidenced by its ability to engage students in problem-solving tasks and interactive learning environments (Altares-López et al., 2024). Through generative AI, students can formulate new hypotheses, make observations, collect various data, and model these data to reach creative outcomes. While the observations and data collection occur in simulated or virtual environments rather than through direct interaction with physical phenomena, these processes still enable students to engage in essential scientific practices. For instance, generative AI can simulate environmental changes, chemical reactions, or complex datasets that students can analyze and interpret. By working with these simulated scenarios, students practice designing experiments, testing hypotheses, and drawing conclusions, fostering their scientific process skills in a controlled yet dynamic learning environment.

In summary, generative AI in science education offers significant opportunities for personalized learning, teacher support, and innovative learning experiences for both students and teachers. These are potential contributions that generative AI could offer to science education; however, scientific studies are required to verify its effectiveness in science education. Since AI literacy is an

emerging field in the twenty-first century, current literature is limited (Ng et al., 2021), and studies demonstrating the contributions of generative AI to science education are also scarce (Cooper, 2023).

Importance of the Study

With the initiation of using GAI in the field of education, numerous criticisms have emerged. One of these is the accuracy of the information produced by GAI. GAI can answer all the questions posed and even provide references. However, the accuracy of these references is debatable because some them added to the generated texts are incorrect. For trial purposes in November 2024, a question was directed to an AI-based research assistant: "What are the contributions of generative artificial intelligence to science education?" A meaningful text was obtained. Despite the text containing seven references, it was revealed that these references were not directly related to artificial intelligence and science education but belonged to articles in different fields. In fact, in one sentence within the text, a reference was given as "Science education is one of the fields that has also been influenced by this transformation (source)"; however, upon examining the relevant source, it was determined that the article was in the field of mathematics and contained no content related to science subjects. This example underscores the potential pitfalls of relying solely on generative AI for academic purposes and highlights the need for studies that critically evaluate the reliability of AI-generated content. Therefore, our study aims to address these gaps by systematically analyzing the reliability and educational potential of GAI in the context of science education. This focus not only contributes to the growing body of research on GAI but also provides practical insights for educators and policymakers.

Studies using generative artificial intelligence in education are increasing day by day (Arık & Seferoğlu, 2024). GAI is being taught as a course in universities and has even been added as a compulsory course to curricula in China. Other countries are also considering including generative AI in their curricula in the near future (Erümit et al., 2024). Preparing students for the age of artificial intelligence requires integrating AI into educational practices in meaningful ways (Miller, 2023). This study specifically contributes to this aim by focusing on how GAI can be effectively utilized in science education while addressing concerns about its reliability and ethical implications. By closely examining generative AI platforms and their applications in science education, this research not only evaluates existing tools but also offers recommendations for developing AI literacy among students and teachers (Ceylan & Altıparmak Karakuş, 2023; Ng et al., 2021).

Ng et al. (2021) consider AI literacy as "knowing and understanding artificial intelligence," "using and applying artificial intelligence," and "evaluating and creating artificial intelligence." Each of these components needs to be present in students for AI literacy; moreover, the ethics of using AI is also an important topic of discussion. This study aligns with these principles by addressing the practical and ethical aspects of integrating GAI into science education, thereby supporting the development of AI literacy (Cheung et al., 2024; Ng et al., 2021).

Purpose of the Study

This study aims to find the application areas of generative artificial intelligence (GAI) in science education and analyze the current research trends in this area. Specifically, it seeks to address the research questions: *What is the use of generative artificial intelligence in science education, and what are the research trends in this field?* This literature review examines how GAI supports knowledge exploration, instructional material creation, and assessment processes in science education, as well as how these applications are implemented. It is based on articles published in the Web of Science database between 2021 and 2024. Along with evaluating the potential benefits of GAI to educational processes and the difficulties faced in classroom applications, the study aims to assess how teachers, pre-service teachers, and researchers perceive its usage in science education. Within this scope, the study discusses the impact of GAI on student achievement, the opportunities it offers for producing learning materials, and its role in analyzing educational processes.

Method

This study is a systematic literature review aimed at evaluating the existing body of knowledge through a rigorous, comprehensive, and structured process. A systematic literature review seeks to summarize, synthesize, and critically evaluate past studies in response to a specific research question

or to address knowledge gaps within a field (Boell & Cecez-Kecmanovic, 2015; Pati & Lorusso, 2017). Compared to conventional literature studies, this approach offers a more comprehensive and precise understanding because it transparently documents all steps of the process and follows a repeatable method from start to finish (Pati & Lorusso, 2017).

Yıldız (2022) outlines the systematic literature review process in three stages: planning the review, conducting and reporting it, and making it available for use. In planning the review, explaining the need for the review and defining the research question are prioritized. Rapid advancements in technology are permeating all areas of life, leading to a diversification of technology-supported learning methods in education, particularly in science education. The contribution of these new technological opportunities to science teaching is a topic worthy of investigation.

Data Collection Process

After planning the systematic literature review, the next step is to conduct it (Yıldız, 2022). Using the keywords “artificial intelligence” AND “science education,” a search was conducted in the Web of Science database, yielding 208 studies. The selection of only the Web of Science database was guided by its inclusion of articles in the SSCI-SSCI Expanded indexes and its provision of reliable citation data across broad academic disciplines. While other databases such as "Scopus, Web of Science, SCIELO, DOAJ, LATINDEX, and REDALYC" (Deroncele-Acosta et al., 2024), "IEEE Xplore, Springer, Taylor & Francis, ERIC, ScienceDirect, Wiley, and Google Scholar" (Almasri, 2024), "Scopus" (Akhmadieva et al., 2023), and "Web of Science and Scopus" (Jia et al., 2024) have been effectively utilized in previous studies, the decision to use only Web of Science in this study was made to streamline the article review process and focus on a manageable dataset. This approach does not negate the value of other databases but reflects a methodological choice aimed at enhancing efficiency without compromising the quality of the review.

The rapid developments in generative AI can lead to research results becoming quickly outdated. For instance, a study conducted with ChatGPT-3.5 found that it was adequate for report formatting and basic information organization but lacked scientific accuracy and original data interpretation skills (Wang, 2023). If this study were repeated with ChatGPT-4 or a more advanced model, it might reveal that these previous shortcomings have been addressed. Therefore, it is crucial that research on the use of generative AI in education is always based on up-to-date data. The inclusion criteria for the study were the most recent articles published in English that examined the applications of generative AI in education. The growing number of studies investigating AI tools' applications in education (Ünsal & Karaoğlan Yılmaz, 2024) distinguishes this study from previous reviews. Additionally, the study explores the contexts in which generative AI has been addressed by researchers and how it contributes to developing AI literacy among students or science teachers.

Data Analysis

The article search based on the criteria yielded 208 articles. The titles and abstracts of these articles were reviewed to assess their alignment with the study's objective. In this context, 33 articles were selected for data analysis. These articles were examined according to four criteria for descriptive analysis: (1) Research Topic and Distribution by Year, (2) AI Methods/Tools Used, (3) Research Context, and (4) Recommendations for Future Research. These criteria were chosen based on their alignment with the objectives of this study, which aimed to systematically analyze the applications of generative AI in science education. Similar criteria have been employed in previous reviews examining educational applications of AI (Deroncele-Acosta et al., 2024; Almasri, 2024). They were also selected to ensure that the analysis provided comprehensive insights into the trends, methodologies, and future directions in the field. As a result of this analysis, it was determined that six articles included review articles and studies unrelated to science education; thus, these articles were excluded from the scope of the study.

Findings

A systematic literature review resulted in the examination of 27 articles, from which the following subgroups were established: (1) academic studies where generative artificial intelligence (GAI) tools are directly used in science education, (2) AI tools used to enhance the effectiveness of STEM

applications in science education, (3) views of teachers or pre-service teachers on artificial intelligence, and (4) other studies.

Academic Studies Where Generative AI Tools Are Directly Used in Science Education

Table 2 summarizes studies where GAI is directly applied in science education. These studies indicate that GAI tools are used as resources for knowledge exploration, material production for classroom applications (e.g., lesson planning, creating assessment rubrics), providing teaching materials to clarify abstract science concepts, and analyzing student products. While ChatGPT and its variants are frequently used, other tools such as Constructed Response Classifier, Automatic Speech Recognition, augmented reality (AR), and intelligent tutoring systems (ITS) are also employed.

Based on the contexts in which these studies were conducted, they can be grouped as follows: (1) researchers and generative AI, (2) the classroom use of generative AI, (3) use by students and teachers for material production, and (4) use of GAI as an alternative instructional strategy in experimental research.

Studies in the first group involve researchers testing GAI tools to examine how accurately these tools perform specific tasks, such as answering science-related questions, assessing student products, and analyzing student drawings. The second group includes applications where students and teachers interact directly with GAI tools, such as using tools that transcribe speech for pre-service teacher education, planning science lessons, and teaching science with augmented reality. In the third group, studies focus on pre-service teachers using AI for lesson planning. Finally, among three quasi-experimental studies, one observed improved writing skills in pre-service teachers, another found increased student achievement through the use of AR and ITS, and the last study reported improved student achievement with the use of a chatbot application.

The findings of the articles in Table 2 provide the following recommendations for future studies: The importance of structuring ChatGPT and other AI tools in education with human guidance has been highlighted. To mitigate the potential negative impact of students viewing ChatGPT as the sole source of correct information, it is recommended to emphasize teacher guidance in classroom use and promote students' independent thinking skills. Additionally, further research is encouraged on the effects of AI in teacher education, lesson planning, and writing skills across diverse sample groups.

The development of AI-supported analytical rubrics and adaptation of three-dimensional assessment methods, as well as enhancing the capacity for generating original content in processes such as laboratory report writing, are also emphasized. The development of automated assessment models covering various scientific representations and technologies supporting epistemic emotions is suggested. More research is needed to use GenAI and ML tools in education more efficiently, reliably, and without bias. Future research should also explore the long-term effects of ITS-AR integration on different student groups and examine the effectiveness of these technologies in face-to-face education across various subjects.

AI Tools Used to Enhance the Effectiveness of STEM Applications in Science Education

This section discusses three studies. First, the study by Bertolini et al. (2023) emphasizes the importance of data-driven approaches in understanding student achievement in STEM education through AI-supported analyses. Factors affecting student success in STEM classrooms were evaluated using Bayesian methods, with AI used not directly as an algorithm or model but as a data-driven tool and framework for predicting student success. AI technologies and machine learning methods are viewed as foundational approaches in predictive analytics used to assess student achievement and retention/dropout trends in STEM classes.

Huang's (2024) study highlights the significance of targeted mobile applications for evaluating educational practices and improving quality within the STEM curriculum. By defining evaluation criteria for mobile applications used in education and analyzing how these applications can be utilized in educational contexts, the study explores the potential of AI applications in education.

Table 2.
Academic Studies Directly Using Generative AI Tools in Science Education

Studies	Research Purpose	AI Methods and Tools Used	Research Context	Recommendations for Future Research
Oh and Lee (2024)	To consider ChatGPT as an independent epistemic agent and conduct epistemic inquiries in this context.	ChatGPT	ChatGPT is treated as an epistemic agent, responding to researchers' questions in a study involving interaction between researchers and AI.	It is suggested that ChatGPT's role in education should be structured under human guidance.
Cooper (2023)	To investigate the potential impacts of ChatGPT on science education and provide a pioneering examination of the pedagogical use of generative AI.	ChatGPT (generative AI, language model)	A study involving interaction between the researcher and AI.	The risk of ChatGPT being perceived as the sole correct source and its potential negative effects on students are discussed.
Okulu and Muslu (2024)	To systematically evaluate the contributions of ChatGPT in lesson planning within teacher education.	ChatGPT (generative AI, language model)	The study explores the potential and contributions of ChatGPT in lesson planning for science teacher candidates.	It is recommended to further develop ChatGPT's applications in teacher education and various lesson planning processes.
Kaldaras et al. (2022)	To examine the potential of AI-generated rubrics in ensuring reliability in scoring based on learning progress.	Constructed Response Classifier (CRC)	The study compares AI-developed rubric analysis of K-12 students' responses with human-based assessment.	Further development of analytical rubrics and adaptation to various three-dimensional assessment methods is recommended.
Halonen et al. (2023)	To enhance interaction and knowledge sharing in education by integrating AI-based digital tools into classroom discussions.	Automatic Speech Recognition (ASR)	Science teacher candidates used AI tools to transcribe spoken language into written text, visualized as digital word clouds during lessons.	It is recommended to develop technologies that support epistemic emotions in the future.
Zhai et al. (2022)	To develop an ML model that assesses scientific thinking skills by evaluating student drawings and written explanations.	Convolutional Neural Network (CNN) and Natural Language Processing (NLP)	ML algorithms were trained on responses from 1,050 middle school students; student drawings were analyzed with CNN, and written explanations were evaluated using NLP methods.	It is recommended to further develop automated assessment models to cover a wider range of scientific representations.
Wang (2023)	To examine the effects of ChatGPT on scientific reporting and the changes in teacher-led student assessment via AI.	ChatGPT (GPT-3.5)	The researcher prepared five different questions to evaluate ChatGPT's potential, analyzing the AI's responses.	Further research is recommended on how ChatGPT can produce more accurate and original content in laboratory report writing.
Ateş (2024)	To examine the effects of augmented reality (AR) and intelligent tutoring systems (ITS) integration on science education.	Augmented Reality (AR) and Intelligent Tutoring Systems (ITS)	A quasi-experimental design was used to study the impact of ITS and AR technologies on middle school students' learning processes of scientific concepts.	Research is recommended on the effects of ITS-AR integration across different student groups and the long-term outcomes of its use.
Cooper and Tang (2024)	To analyze how GenAI tools visually represent science classrooms and science educators.	DALL-E 3 (image generation), ChatGPT (text analysis and content creation)	Researchers used ChatGPT and DALL-E 3 to produce and analyze two comprehensive illustrations.	It is recommended to work on reducing bias in GenAI-generated content and to develop methods that enhance diversity in educational representations.

Table 2.
Continued

Studies	Research Purpose	AI Methods and Tools Used	Research Context	Recommendations for Future Research
Zhai (2021)	To reveal how machine learning can contribute to innovative assessment practices in education.	Machine Learning (tools like ChatGPT)	The author analyzed how laboratory reports can be assessed by AI.	Further research is recommended for the more efficient and reliable use of ML in education.
Topal et al. (2021)	To examine the effects of an AI-supported chatbot application in 5th-grade science classes.	Chatbot supported by Natural Language Processing (NLP)	The study investigated the impact of a chatbot developed for the topic of states of matter on students' achievement and learning experiences in a 5th-grade science class.	It is recommended to explore the use of chatbots in different subjects, assess their effectiveness in face-to-face learning environments, and examine their long-term effects.
Haudek and Zhai (2023)	To examine the performance of machine learning models in assessing scientific argumentation.	Constructed Response Classifier (CRC)	Data developed to assess scientific argumentation skills at the middle school level were used.	Further research is recommended on scoring high-level and complex structures with ML.
Garofalo and Farenga (2024)	To examine teachers' perceptions of the use of GenAI in education.	Chatbots (ChatGPT, Bard, Bing)	24 middle and high school science teachers were studied through focus group interviews and surveys.	It is recommended to research teachers' adaptation processes to AI technologies and the challenges encountered in integrating GenAI into education.
Li and Ironsi (2024)	To examine the impact of ChatGPT on developing writing skills in pre-service teachers.	ChatGPT	Conducted using a mixed-method experimental approach, comparing the writing skills of groups exposed to AI and digital literacy strategies.	It is recommended to investigate the effects of ChatGPT on other dimensions of writing skills and to conduct studies with a larger sample.
Lee and Zhai (2024)	To examine the integration of ChatGPT into lesson planning in science education.	ChatGPT	Pre-service teachers used ChatGPT for functions such as information gathering, instructional support, and providing feedback.	It is recommended to emphasize the role of teacher guidance in classroom use of ChatGPT and to foster students' independent thinking skills.

Lastly, Henze et al. (2022) aim to provide insights into how digital STEAM tools can be effectively utilized in teacher education and to increase teachers' interest in these technologies.

A synthesis of these three studies reveals that AI tools play a multifaceted role in enhancing STEM education. While Bertolini et al. (2023) focus on predictive analytics to support student achievement and retention, Huang (2024) demonstrates how AI-powered mobile applications can improve educational quality and practices. Henze et al. (2022) extend this perspective by exploring how digital tools, including AI, can foster teacher engagement and training in STEAM education. Collectively, these studies underscore the versatility of AI tools in STEM education, highlighting their potential to improve educational outcomes, empower educators, and support data-driven decision-making processes.

Views of Teachers or Pre-Service Teachers on Generative Artificial Intelligence

This section examines the perceptions, awareness, and readiness of teachers and pre-service teachers to integrate generative AI tools, particularly in science education. Monteiro et al. (2024) investigate the perceptions of K-12 science teachers in Brazil regarding ChatGPT's potential in science education. While ChatGPT was not directly used, teachers expressed both optimism and skepticism about its role in improving assessment practices and supporting differentiated instruction. The study highlights that although teachers recognize generative AI's potential, they also point to concerns about its impact on the accuracy and credibility of student learning in science contexts.

AlKanaan's (2022) study explores pre-service science teachers' awareness of AI integration in education. The findings reveal a low level of awareness, indicating a significant gap in training and readiness to employ AI tools. The study emphasizes the necessity of preparing future teachers to understand AI's role in enhancing personalized learning, fostering scientific inquiry, and addressing complex concepts in science education. The need for professional development programs targeting AI literacy is strongly recommended.

Antonenko and Abramowitz (2023) investigate misconceptions held by K-12 science teachers about AI. Their findings reveal that many teachers incorrectly equate AI to human intelligence or view it as entirely autonomous. These misconceptions could hinder effective integration of AI tools in teaching scientific concepts such as climate modeling or data analysis. The study underscores the importance of dispelling myths through targeted professional development programs, as teachers' misconceptions can inadvertently perpetuate inaccuracies in student learning.

Garofalo and Farenga (2024) examine secondary science teachers' attitudes toward generative AI amidst its rising popularity. Teachers expressed cautious optimism but raised ethical concerns about plagiarism and the definition of original thinking in the context of AI-generated outputs.

These studies collectively highlight a spectrum of perspectives on generative AI in science education. Teachers and pre-service teachers generally recognize the transformative potential of AI but lack sufficient training and understanding to fully integrate it into science classrooms. Misconceptions about AI's capabilities and ethical implications further complicate its adoption. To address these challenges, comprehensive teacher preparation programs are needed to build AI literacy, dispel misconceptions, and emphasize the application of AI tools in fostering inquiry-based and personalized learning. These insights underscore the critical role of generative AI in reshaping science education, provided that adequate support and resources are made available to educators.

Other Studies on the Use of Generative Artificial Intelligence in Science Education

This section summarizes findings from various studies that address the use of generative AI in science education. Erduran and Levrini (2024) investigate the impact of AI on scientific practices and explore how these effects can be transferred to science education. This study examines the role of AI in scientific processes such as hypothesis generation, data analysis, and modeling, evaluating the potential contributions of these applications to science education.

Barelli et al. (2024) conducted a study not directly related to science education but focused on the epistemic dimensions of AI. This research addresses AI paradigms like deep learning and logical programming as tools to enhance students' epistemic understanding, offering a framework that can support data science and computational thinking skills within the science education context. Cheung et

al. (2024) conducted a systematic review examining the epistemic relationships between AI and science education from 2012 to 2023. This study analyzes the influence of AI on scientific knowledge production, evaluation, and critique processes, providing insights into how these relationships could be approached in K-12 education. Gouvea (2024) focuses on the ethical dimensions of AI in science education. The study discusses potential biases in machine learning-based assessment systems and emphasizes the importance of using these technologies with ethical responsibility. It also highlights the need for teachers to consider students' individual differences when using AI-based assessment tools. Tang (2024) examines the role of language in meaning-making processes to support GenAI usage in science education from a language and literacy perspective. The study provides recommendations on how GenAI can be integrated into the transmission of scientific knowledge structures to students. Finally, Heeg and Avraamidou (2023) systematically examine the use of AI applications in school science education and their impact on instructional processes. This study evaluates the focus areas of AI tools within content areas and their contributions to learning outcomes.

These studies address various aspects of generative AI in science education, offering important insights into the pedagogical, epistemic, and ethical dimensions of its applications in the field.

Discussion

This study examined 27 articles published between 2021 and 2024 in the Web of Science database that focused on the direct use of generative AI in science education. Publications from 2024 constitute 51.85% of the total, followed by 25.93% in 2023, 14.82% in 2022, and 7.41% in 2021. This distribution shows a rapid increase in articles on generative AI tools in science education. This increase is consistent with Ünsal and Karaoğlan Yılmaz's (2024) findings in their literature review on AI and deep learning in education from 2019-2023, where they noted that most of the 55 articles reviewed were published in 2023. Overall, the use of AI in education continues to grow (Arık & Seferoğlu, 2024; Bahroun et al., 2023). One reason for this increase is the efforts of K-12 teachers to enhance students' AI literacy using diverse pedagogical methods (Ng et al., 2022).

In this study, generative AI is discussed as a source for knowledge exploration, a tool for producing supplementary classroom materials, and a resource for evaluating student products. Compared to studies from previous years, recent studies are observed to integrate more classroom applications. For example, STEM-focused approaches to science teaching (Bertolini et al., 2023; Henze et al., 2022; Huang, 2024) are increasingly subjects of AI-supported research. Publications from Scopus grouped by Akhmadieva et al. (2023) indicate similar themes. In science education, AI is widely used for "enhancing learning experiences, advancing assessment processes, and supporting educators." According to Almasri's (2024) review, students in experimental groups demonstrated significantly higher achievement in academic tests than those in control groups, and the achievement gap between high- and low-performing students was found to decrease in AI-supported learning environments. In summary, AI’s contributions to education include providing personalized learning support, giving students instant feedback, and simplifying complex information. This transformative role in making complex topics more understandable significantly impacts the educational process (Bahroun et al., 2023).

Another research approach on generative AI in science education involves testing the accuracy of responses generated by tools like ChatGPT. Although the contributions of generative AI to science education are frequently highlighted, it is noted that AI is still evolving and should be used with ethical considerations. This raises concerns about validity and reliability, which could create biases and limitations in classroom applications (Almasri, 2024). To address this, it is recommended to critically evaluate the AI tools used and adapt them to teachers' instructional contexts (Cooper, 2023). In summary, careful assessment of the information and products generated by generative AI tools is essential before transferring them to educational settings.

The study also includes findings from articles exploring teachers' and pre-service teachers' views on generative AI. Teachers’ perspectives on generative AI, particularly ChatGPT, reflect concerns, misconceptions, and knowledge gaps. Pre-service teachers' low awareness of AI’s applications in science education is noteworthy (AlKanaan, 2022). This deficiency is attributed to a lack of emphasis on AI in university programs and a scarcity of training courses. Another factor contributing to pre-service teachers' low awareness is a lack of motivation to improve themselves in this area, which limits

their ability to fully benefit from AI's potential in education (AlKanaan, 2022). In another study, many teachers were found to struggle with understanding the importance of AI and the structural differences between algorithms and held several common misconceptions, for example, AI is expensive, can learn on its own, and is always unbiased. Additionally, teachers' limited knowledge of AI's ethical dimensions or uncertainty regarding these aspects impacts their implementation processes (Antonenko & Abramowitz, 2023). According to teacher perspectives, some teachers view ChatGPT as a useful tool, while others perceive it as a risk for plagiarism (Monteiro et al., 2024). Teachers particularly raise ethical concerns regarding plagiarism, information accuracy, and preserving original thought (Garofalo & Farenga, 2024). These findings indicate that teachers are questioning how to apply AI in the classroom rather than fully embracing it. In summary, teachers' attitudes toward AI are shaped by knowledge gaps, ethical concerns, and misconceptions. While they recognize AI's potential in education, they are also concerned about potential challenges and ethical risks in its application.

Conclusion and Recommendations

According to this study, generative AI is becoming a more and more important tool in science education, helping to digitize the learning process. In science classrooms, GAI tools are utilized to create learning materials, offer content that is personalized for each student's unique needs, foster scientific process skills, and help students solve problems. GAI-supported solutions have demonstrated promise in enhancing student accomplishment, streamlining complex information, and offering instant feedback, especially in STEM and scientific education. Furthermore, this technology supports the teaching process by saving teachers time and providing innovative lesson preparation ideas.

However, there are some practical and ethical difficulties associated with viewing GAI as a trustworthy information source in educational contexts. Teachers must be careful while directing students because of the limits of GAI tools like ChatGPT with regard to information veracity, source credit, and ethical duties in education. Knowledge gaps, misunderstandings, and ethical issues influence how instructors and pre-service teachers view GAI, which might cause hesitancy when it comes to using GAI in the classroom. Teachers' willingness to actively incorporate GAI into their lessons may be constrained by worries about plagiarism, information accuracy, and preserving original thought in particular.

In conclusion, these tools should be critically assessed, modified to fit the pedagogical settings of teachers, and used in ways that encourage students to think independently in order to be used in science education. Although the potential advantages of GAI in educational processes can be increased, it is imperative to structure its use with ethical concerns and implement it under the supervision of teachers.

Future studies should concentrate on creating thorough teacher training curricula to facilitate the more dependable and efficient application of GAI in scientific instruction. In addition to ensuring safer and better-informed classroom uses, these programs ought to assist educators in appropriately evaluating GAI's potential within a pedagogical framework. Furthermore, research is required to assess GAI's long-term effects on education and investigate its suitability for use with various student populations. Creating real-world examples that prioritize teacher guidance can also provide light on GAI's ethical obligations and educational contributions in the classroom.

In light of this, methods for reducing the moral hazards connected to GAI-supported education should be developed, and its application as a means of fostering critical thinking in the classroom ought to be encouraged. GAI can foster critical thinking by providing students with opportunities to engage in inquiry-based learning, analyze complex problems, and generate creative solutions. For instance, GAI-powered simulations and problem-solving tools can guide students through scientific scenarios where they must evaluate data, identify patterns, and draw conclusions. This process helps students develop analytical skills and encourages them to question assumptions, consider alternative perspectives, and make evidence-based decisions.

For GAI to be a useful tool for reducing teachers' workloads, offering individualized learning support, and simplifying difficult scientific topics in science education, more study is required. The development of educational manuals will also be advantageous. These kinds of studies will be useful tools for teachers, promoting the use of technology in science instruction.

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