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Advancing Science Teacher Education through Artificial Intelligence: A Systematic Review of Innovations, Challenges, and Future Perspectives

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Abstract

A review of the literature using the PRISMA 2020 framework conducts a systematic review of the integration of the use of artificial intelligence (AI) in science education as it pertains to teacher education. Research conducted from 2015 to 2025 from major academic databases to conduct an extensive systematic literature review identified a major change in approach from traditional Intelligent Tutoring Systems (ITS) toward Collaborating with AI and Generative AI. The synthesis of the findings produced seven significant themes: AI Literacy; Personalized Learning; GenAI Apps; Virtual Labs; AI-Assisted Assessment; Inquiry-Based Science Learning; and Professional Development. Although artificial intelligence has tremendous potential for providing engaging individualized educational experiences, there are several hurdles to overcome when incorporating AI into school-based learning environments. These challenges can take the form of technical inaccuracies;

issues related to pedagogy (e.g., cognitive overload); and ethical considerations (e.g., algorithmic bias and data privacy). As a result, there is a very large divide between the potential use of artificial intelligence as a technological medium and the extent to which teachers actually use artificial intelligence in their classrooms. The assessment reaches the conclusion that overall it will be imperative to conduct a comprehensive structural reform to teacher education curricula to foster the development of AI literacy in all three forms (theoretical, practical, and ethical judgement), most prominently through frameworks such as AIknowSense. Moving forward, educators will play an increasingly different role as facilitators rather than as providers of information; rather, they will design learning environments that include AI as a cognitive scaffold. Future research efforts should primarily consist of longitudinal studies and hybrid AI ecosystems, specifically combining large-scale language models or AI tools for learning and instruction with simulations and augmented reality for the purpose of developing an equitable, inclusive and evidence-based approach to science education.

Keywords: artificial intelligence, science pedagogy, teacher education, AI literacy, generative AI.

Introduction

The foundation for economic growth is based on teaching children about the concepts of science; but unfortunately, in many cases, these same concepts can create confusion due to their abstract nature and/or incorrect understanding. With the introduction of AI, education systems are going through significant changes, providing an opportunity to imprint science-based learning onto students through personalized, adaptation, and immersive methods.(Azizi et al., 2026; Fayzullina et al., 2025). AI has rapidly evolved from intelligent tutoring systems to using generative chatbots (e.g., ChatGPT) to help increase student engagement and achievement, while easing the administrative burden of teachers. Teacher education is integral to advancing this technological evolution as much of the successful implementation of AI depends on how teachers can align their pedagogy and integrate technology with their own teaching. Teachers are increasingly

challenged to redefine themselves as facilitators of learning and to design learning environments that utilize AI to support inquiry-based and experiential learning. There is, however, a continuing gap between the possibilities of technology versus what occurs in the classroom; most teachers report a lack of confidence and experience with teaching using AI. Additionally, there are many ethical, technical, and pedagogical issues related to the implementation of AI in education (e.g., algorithmic bias, data privacy, and risk of overuse). Although numerous studies have been published on the effects of AI, studies specifically focused on the long-term effects of AI on the education of science teachers are few and far between. This article is a systematic literature review of current research trends and provides a comprehensive overview about the current status of teacher education with respect to AI-supported science pedagogy. Additionally, this article identifies the major barriers and emerging best practices to provide a conceptual framework for developing future-ready, inclusive, and ethical science instructional practices (Fayzullina et al., 2025; Salleh et al., 2026).

Literature Review

Artificial Intelligence in Education (AIED)

AI used in education refers to both robotic and digital systems that simulate cognitive abilities similar to humans. AIED has gone from computer-assisted learning in the 1960s to Generative AI and large-scale language models (e.g., ChatGPT) and currently exists. In educational settings, key types of tools are intelligent tutoring systems (ITS), educational chatbots, analytics in learning, and adaptive learning platforms, which provide customized content delivery (Alhusaiyan, 2025; Doğan & Şahin, 2024; Kavitha & Joshith, 2024; Peng & Li, 2025).

Science Pedagogy

The purpose of science education is to help students learn to use scientific reasoning in developing their understanding of the world. In addition, Inquiry-Based Learning is a method of teaching that emphasizes inquiry as a key component of student-centered instruction. Instruction is also supported with Project-based Learning and cooperative problem solving (Antonio, 2026; Peng & Li, 2025; Rehman et al., 2025; Rodríguez-Ortiz et al., 2025).

AI and Science Education

By having immersion-style experiences that utilize AI technology as a means to improve classroom instruction, students will receive more accurate and timely feedback from their teachers. Virtual labs and simulations allow students to perform actual experiments safely, while still visualising the abstractness of certain concepts as they relate to science. Within the field of science education, Intelligent Tutoring Systems (ITS) provide students with personalized assistance by monitoring each student's performance and providing assistance to correct their conceptual misunderstandings. ITS also help to facilitate the individualised learning process by providing individualised instructional pathways based on a students' existing knowledge and the rate at which he/she learns.(Azizi et al., 2026; Erümit & Sarıalioğlu, 2025; Kavitha & Joshith, 2024).

AI in Teacher Education

In order for educators to be able to successfully implement artificial intelligence (AI) solutions into their classrooms, they must have a working knowledge of AI, which also includes understanding both how to use AI and what the ethical implications are for the use of AI. While the majority of teachers recognize that there are benefits to using AI in the classroom, the majority of educators also believe that they are unprepared to implement AI due to a lack of experience and confidence, coupled with their fears of using AI. In order to effectively train teachers with the necessary skills to effectively implement AI into the classroom, professional development programs are necessary to develop the skills to link AI tools with instructional goal(s), and to properly evaluate the ethical implications of using the AI tools.(Adil, 2025; Techakosit et al., 2025; Yan et al., 2025; H. Zhang et al., 2025).

Theoretical Foundations

Constructivism is considered a basis for viewing learners as being actively involved in developing their own knowledge through interaction. Sociocultural Theory emphasizes the social aspect of learning and that learning is mediated by the use of cultural tools (e.g., artificial intelligence). The TPACK Framework (Technological Pedagogical Content Knowledge) is used to evaluate the integration of technology into a particular

subject area by teachers. Emerging frameworks related to AI and pedagogy provide a way to connect advancements in technology with evidence-based instructional practices.(Akhlida et al., 2026; Nguyen & Thai, 2023; Tariq et al., 2024; Wekullo, 2026; Zheltukhina et al., 2023).

Research Gap

According to recent research, the majority of research done has been conducted on AI as it pertains to universities, which results in a major gap in research on K-12 education. There are only a few aggregate studies focused on the integration of AI into instructional practices of science educators. Additionally, there have been very few studies conducted that explore the long-term effects of AI on teacher preparation and professional development. Lastly, there are very few comprehensive reviews that synthesize the most prominent emerging trends associated with AI's use, including ethical issues and empirical evidence regarding its effects on actual student achievement outcomes.

Methodology

Research Design

This policy uses a Systematic Review of the Literature (SRL) structure, which is a deliberate and methodical way to discover, assess, and combine the body of evidence in the form of research already conducted within the field of Science Education and Teacher Education. An SRL is used to put together a reliable and consistent framework for finding and creating a visual representation of how the landscape of artificial intelligence (AI) in science education and how it has been used in the training of teachers, has developed over time. Traditional methods of reviewing scientific literature do not eliminate or reduce researcher bias and provide an accurate source of authenticated evidence; however, as the educational community is looking to identify emerging patterns and possible pedagogical changes, and where holes exist in current research(Arifin et al., 2025; Effendi et al., 2025; Iliasova et al., 2025; Kumar et al., n.d.; Y. Zhang & Zhu, 2023).

PRISMA Framework

The review is conducted in accordance with the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The PRISMA framework ensures methodological rigor through a standardized four-stage process: identification, screening, eligibility, and inclusion (Almonacid-Fierro et al., 2023; Alshammari & Alhamazany, 2026).

Identification: Initial records are retrieved from electronic databases using a predefined search string.

Screening: Duplicate records are removed, followed by a review of titles and abstracts to exclude irrelevant studies.

Eligibility: Full-text versions of the remaining articles are assessed against specific inclusion and exclusion criteria.

Inclusion: The final set of studies that meet all criteria is selected for qualitative and quantitative synthesis.

Databases

To ensure comprehensive coverage of both technological and pedagogical perspectives, searches are conducted across several major academic databases: Scopus, Web of Science (WoS), ERIC, IEEE Xplore, and Google Scholar. Scopus and WoS are utilized for their broad multidisciplinary coverage and extensive citation networks, while ERIC provides a specialized focus on education literature. Google Scholar is employed as a supplementary tool to identify potentially overlooked empirical studies (Adil, 2025; Margot & Kettler, 2019).

Inclusion and Exclusion Criteria

The following table summarizes the criteria used to filter the literature to ensure the study focuses strictly on the intersection of AI, science pedagogy, and teacher education.

Table 1
Inclusion and Exclusion Criteria

Criterion	Inclusion Criteria	Exclusion Criteria
Study Type	Peer-reviewed empirical studies (qualitative, quantitative, or mixed methods)(Xiaodi et al., 2024).	Non-peer-reviewed sources (blogs, editorials), trade magazines, and unpublished theses(Xiaodi et al., 2024).
Topic Focus	AI-supported science pedagogy (Biology, Chemistry, Physics) within science instruction(Azizi et al., 2026).	Studies focused solely on technical AI development without pedagogical or educational implications(Azizi et al., 2026).
Target Group	Pre-service or in-service science teachers and teacher education programs(Fayzullina et al., 2025).	Studies focused only on general student performance without examining teacher roles or training(Fayzullina et al., 2025).
Timeframe	Articles published between 2015 and 2025 to capture modern Generative AI and adaptive systems(Azizi et al., 2026).	Studies published before 2015(Azizi et al., 2026).
Language	Full-text articles published in English(Adil, 2025).	Non-English publications or articles without accessible full texts(Azizi et al., 2026).

Data Extraction Procedure

Data from the selected studies are extracted systematically using a standardized extraction form or spreadsheet. The following information is recorded for each study:

Bibliographic details: Authors, year, country, and journal name.

Contextual features: Scientific discipline (e.g., Physics, Biology), educational level (K-12 or Higher Education), and target participants (pre-service or in-service teachers).

AI Integration: Type of AI tool used (e.g., chatbots, ITS, virtual labs) and its pedagogical role (e.g., assessment, personalized feedback).

Outcomes: Key findings regarding teacher readiness, AI literacy, instructional effectiveness, and identified challenges.

Data Analysis

The extracted data undergo a multifaceted analysis to address the research objectives.

Descriptive Statistics: Frequency and percentage distributions are used to analyse bibliometric trends, such as annual publication status and geographical distribution(Zheltukhina et al., 2023).

Thematic Analysis: Thematic analysis was completed in accordance with Braun and Clarke (2006) guidelines; specifically, a thematic synthesis was conducted, which utilized initial open coding and axial coding to find patterns in AI-supported pedagogy and further develop these patterns into higher order themes, (e.g., ethical issues, technology infrastructure, teacher competencies)(Fayzullina et al., 2025).

Content Analysis: A content analysis consisted of a systematic examination of the ways that AI tools are functioning and helping to develop the types of trends and directions for future research. This integrated approach also provides a more nuanced understanding of how AI will help transform the preparation of science teachers(Akhilda et al., 2026).

Results And Thematic Analysis

A thorough review of the literature has indicated that AI integration into science education is a quickly growing area of research. The progression has seen a shift away from the use of traditional intelligent tutoring systems (ITS) to embracing generative AI (GenAI)(Fayzullina et al., 2025). The remaining sections summarise these findings along seven key themes to provide an overview of the current state of AI-assisted science teaching, as well as preparing teachers for teaching science with AI.

Theme 1: AI Literacy among Science Teachers

AI Literacy in Education refers to an understanding of artificial intelligence concepts and theories, and also the understanding of the data associated with these concepts and theories. In addition, this understanding includes the ethical use of technology to

provide educational opportunities in science education. To have AI literacy as an educator a person must possess three types of knowledge about AI, which are the episteme, techne, and phronesis(Arifin et al., 2025). While teachers generally demonstrate good awareness and possess positive attitudes towards AI; they do not feel prepared to utilize the technology due to a perceived lack of technical proficiency with assessing AI output. This creates a need for instructional structure/models to equip teachers to assess Yang-produced material as an evaluation tool instead of just using AI-produced materials(Fayzullina et al., 2025).

Theme 2: Personalized Learning

AI also acts as a critical facilitator of personalized learning (PL) in the area of science education by customizing how materials are presented and what instruction is used to match the individual paths of each student(Akhilida et al., 2026). Machine learning algorithms and natural language processing analyze individual student performance and provide various forms of adaptive feedback. In addition, machine learning algorithms will produce recommendations for other content based on an individual's previous work, allowing teachers to customize the learning experience to meet each student's unique learning needs(Fayzullina et al., 2025).

Theme 3: Generative AI in Science Education

The emergence of Generative AI technology (including but not limited to Large Language Models such as ChatGPT or GPT-4) has had a significant impact on many areas of learning. Use of Generative AI tools is helping to grow the amount of content created, lesson plans created, and the number of ways to explain science(Wekullo, 2026). However, there are also challenges that exist when using Generative AI (and its current form) based upon the challenges researchers have identified regarding errors within these types of AI applications, such as hallucinations or inaccurate answers when solving complicated yet subjective types of issues (e.g., chemistry and physics). As a result, if a teacher uses Generative AI in a manner that Szalkowski et al. (in 2021) describe - as a "teacher's aide," which allows for the reduction of teachers' administrative workloads - it is incumbent upon that teacher to carefully investigate and verify by checking the accuracy of the conceptual answers generated through the

Generative AI software program to minimize the potentiality of AI-giarism (the misuse of or incorrect application of) and to encourage independence in their students(Fayzullina et al., 2025; Kavitha & Joshith, 2024).

Theme 4: Virtual Laboratories

The use of virtual labs in conjunction with AI (artificial intelligence), AR (augment-ed reality) and VR (virtual reality) allows students an opportunity to safely, easily, and affordably conduct real-world science experiment while developing a deeper understanding of the subject matter. Virtual lab simulations can also serve as a training tool for pre-service teachers trying to teach in ways that are responsive to students and lab safety(Akhilda et al., 2026; Fayzullina et al., 2025).

Theme 5: AI-Assisted Assessment

The development of AI Technology in Education ,AI has altered how instructors evaluate student's work and allowed for the automation of evaluation for many different types of assignments, including longer ones, such as essays or lab reports, which can now have their grades determined via an automated process(Kavitha & Joshith, 2024). Automated grading aids efficiency and enables consistent, timely student feedback to enable error correction prior to receiving a final assignment grade. Researchers also presently use predictive analytics to identify "at-risk" students so they can access needed supports/interventions. Many researchers question whether overall quality of automated grading will be greater than traditional "human" grading results; hence both grading processes should complement each other; time savings via automated vs. teacher's judgement(Fayzullina et al., 2025; Nguyen & Thai, 2023).

Theme 6: Inquiry-Based Science Learning

Inquiry-Based Learning is an essential part of any modern science learning environment. IBL is supported by AI tools that facilitate questioning, exploration and reasoning through interactive simulations and data support that comes from data analysis agents. In addition, studies have shown that students' inquiry skills are developed by using AI. Adapting IBL teacher education programs will also allow future teachers to support students' engagement through digital forms of inquiry by providing access to AI as a mediator(Fayzullina et al., 2025; H. Zhang et al., 2025).

Theme 7: Professional Development

Teachers need robust Professional Development (PD) before or after entering the profession, offering tech competencies, alignment with pedagogy, ethical decision-making, reflective practice, collaborative lesson design, and viewing AI as cognitive scaffolding. With many mundane tasks being automated, the teacher's role is shifting from being the primary information source to architect of the learning environment facilitating human-AI collaboration. Equally important, the literature shows how educators need continuing training to connect future technological possibilities to classroom reality today (Fayzullina et al., 2025; Yan et al., 2025).

Summary of Thematic Findings

The synthesis of the above results points to the transformative capacity of AI technologies with regard to science teaching through providing a personalized, immersive, and data-driven means of delivering instruction as one of its many advantages. However, the implementation of AI technologies in the context of science education will be challenged by a number of technical, ethical, and infrastructure barriers (Techakosit et al., 2025). Teacher education needs to develop future-ready teachers who have an ample AI Literacy to understand the complex social and pedagogical ramifications of the use of AI technologies. The results of this research suggest that AI technologies should supplement the people-oriented aspect of teaching such as mentorship, emotional support, and ethical guidance rather than replacing those aspects (Fayzullina et al., 2025).

Discussion**Comparison with Previous Studies**

The outcomes from this review support past research demonstrating that AI has the ability to change how students excel in school, create motivation to learn and keep students engaged with science subjects (Kavitha & Joshith, 2024). Literature dating back to many years suggests that Intelligent Tutoring Systems (ITS) and adaptive systems provide customized feedback to student(s) and positive results in academic success for those students using this type of system (H. Zhang et al., 2025). The literature beyond

recognizes a rapid transformation to Generative AI (GenAI). Researchers are utilizing more Generative AI researchers such as Large Language Models (LLM) like ChatGPT, which are dominating the research area of 2023 to provide lesson plans and create content in ways not possible through typical adaptive instructional systems(Azizi et al., 2026). However, the level of adaptation through the use of GenAI provides new opportunities for lesson development / content creation that did not exist for traditional ITS. Additionally, how the use of GenAI presents risks for delivering inaccurate data to users as compared to traditional ITS risk(Munaye et al., 2025).

Interpretation of Major Trends

A main trend that has been identified is that AI is transitioning from being just a tool that supports automation, to being used as a cognitive scaffold in the process of collaboration between humans & AIs. Additionally, AI is being used in conjunction with various other digital environments such as virtual labs or augmented realities to visualize scientific phenomena that are abstract(Peng & Li, 2025). The researchers have also identified a major shift from creating AI tools that are student-oriented and creating AI tools that are teacher-oriented due to the recognition that AI is only as successful as the way in which it is used by teachers (i.e., the pedagogical alignment of teachers and their ability to integrate into their classroom)(Rodríguez-Ortiz et al., 2025). At the same time, the research on this topic tends to be focused on higher education rather than K-12 education, which has highlighted a continued lack of preparation for science teachers in K-12(Erümit & Sarıalioğlu, 2025).

Implications for Teacher Education

- Because of the evolving nature of teacher preparation, educational programs must revamp their existing curricula to align with current teaching practices(Techakosit et al., 2025). Although most science educators like science, they have little formal experience to feel comfortable using and evaluating AI technologies with the same level as other tools (e.g., lab equipment). Therefore, even though many have good attitudes toward incorporating AI into their classrooms, they have low levels of confidence about using them(Adil, 2025).

- At this time, teacher preparation programs must focus on helping teachers become "informed evaluators," which means that teachers will be prepared to evaluate AI-generated materials (including content). Thus, teachers will be able to serve as facilitators for collaboration between AI and people—rather than merely being the only source of information(Alshammari & Alhamazany, 2026).
- Lastly, as AI is created and used, there is a pressing need for rules governing both fairness and accessibility. To address this, teacher education programs will need to create sufficient governance mechanisms to address issues related to the adoption of AI technologies, including algorithmic bias, data protection, and the digital divide; these mechanisms will help to guarantee the moral and fair incorporation of AI into the classroom(Munaye et al., 2025).

Challenges

The integration of Artificial Intelligence (AI) into science pedagogy within teacher education faces a multifaceted array of challenges. These barriers are categorized into technical, pedagogical, ethical, and institutional domains.

Technical Challenges

Currently, some of the biggest technical hurdles facing AI are how consistently and accurately its output will compare to what a human produces. AI is known to produce "hallucinated" or incorrect outputs, especially when performing complex reasoning for various types of scientific calculations, such as mathematics and diagrams. This occurs even more frequently in the domains of physics and chemistry. AI has many challenges processing natural language (NLP) because of the nuance that is present in every language and culture(Erümit & Sarıalioğlu, 2025). The presence of these differences in culture and language causes breakdowns in communication with humans and a failure to recognize the different backgrounds that individuals bring with them when communicating. Finally, many organizations face difficulty in deploying AI technology because of the high demand of purchasing hardware and obtaining high-bandwidth internet connections(Yan et al., 2025).

Pedagogical Challenges

One significant issue is that there is no targeted subject implementation for using an AI tool as just a "technical add-on". Rather AI is not being integrated deeply enough into current science curriculum. Consequently, students may be exposed to an overwhelming multicultural or multi-dimensional and or multi-functional nature of AI that makes it difficult for them to process or understand what they are experiencing(Fayzullina et al., 2025). Furthermore, by relying too heavily on technology or automated tools, students may develop cognitive offloading. This can inhibit a student's ability to make informed decisions through critical thinking; developing sound scientific arguments; and cause students to become less capable of independently solving problems and creating their own original thoughts and reasoning(Salleh et al., 2026).

Ethical Challenges

There are two main ethical issues associated with AI platforms: data privacy and data security. AI platforms generally make use of personal student information, but most do not effectively communicate how they obtained consent or provide adequate safeguards for the data(Alshammari & Alhamazany, 2026). All users of AI platforms face challenges related to algorithmic bias; training data sets may unintentionally propagate biases related to gender, race or ideology, thereby causing impediments to a science education that occurs within a context of inclusion. Additionally, as generative AI usage increases, concerns around academic integrity rise as well as difficulty in detecting new forms of advanced plagiarism(Erümit & Sarıalioğlu, 2025).

Institutional Challenges

There are many obtainable barriers to using AI tools for educators such as lack of resources, minimal teaching practice, high cost to implement AI and low income and rural communities are also limited in infrastructure. All teachers must create clear ethical guidelines for the use of AI as well as have effective and appropriate methods of teaching.(Munaye et al., 2025).

Future Direction

- Future research should place emphasis on longitudinal and large-scale empirical investigations in order to examine the lasting effects of AI on academic

performance, teacher autonomy, and conceptual change rather than relying solely on short-term observations. Longitudinal and large-scale empirical studies are necessary in order to better inform curriculum reform in teacher education; the goal will be to move from general tool awareness to AI literacy with respect to prompt engineering, ethical decision making (i.e., AIknowSense), and discipline-specific applications of pedagogy.

- The development of hybrid artificial intelligence ecosystems that combine large language models, virtual laboratories and simulations, and augmented reality to create immersive and inquiry-based learning environments for students' individual zones of proximal development is being supported by scholars. In addition, research should focus on developing models for human-AI collaboration as a means to use AI as a cognitive scaffold or thought partner in facilitating rather than replacing the critical human components of mentorship, emotional support, and interactive guidance.
- In order to achieve equality in education and inclusion, there is a considerable need for greater research and expansion into K-12 classrooms, especially in low-resource areas, with respect to addressing both the digital divide and algorithmic bias through the use of co-designing together with historically marginalised learners. Lastly, establishing ethical frameworks and governance policies that are standardised will be critical to ensure the privacy of data, to prevent 'AI-giarism', as well as to ensure that academic integrity is maintained in the use of AI-supported science pedagogies. To close the gap between technological development and pedagogical strategies will be critical to developing context-sensitive AI solutions that can address the diversity of educational needs.

Educational Implications

- A restructuring of teacher education also needs to happen because of the new integration of Artificial Intelligence (AI), into science education. To do so, the first thing that must happen at institutions is an overhaul of the current curriculum, moving away from general knowledge of tools and into specialized

literacy around AI: the theory (episteme), how it is used (techne) and how it is evaluated (phronesis). As part of this effort, AIknowSense and AIethiGuard frameworks need to be added to prepare future educators to use prompt engineering skills and to evaluate AI outputs with more thoughtfulness(Şenay, 2025).

- In addition, the function of educators is changing from essentially providing information to designing learning environments and facilitating human-AI collaboration. The shift also requires ongoing professional development focused on pedagogical alignment, rather than just the technical skills associated with using AI. Educators must learn how to utilize AI as a cognitive support, rather than being called a "thought crutch" by using generative tools to enhance rather than replace critical thinking and inquiry-based reasoning(Alshammari & Alhamazany, 2026).
- The need for equitable and inclusive governance frameworks regarding educational standards will help guarantee equitable science instruction. Government and educational institutions must implement policy protections concerning data privacy, AI-related plagiarism, and addressing the digital divide experienced by under-resourced areas. In addition, scholarship advocates for developing hybrid ecosystems of AI, such as large language models using virtual labs and augmented reality to create immersive experiences that help students learn based on data(Peng & Li, 2025).

Conclusion

This systematic review, conducted using the PRISMA 2020 framework, found that artificial intelligence (AI) can be a transformative agent in science education by providing personalized and immersive learning opportunities that have never been possible before. Through a synthesis of evidence from teacher preparation programs, it supports a shift away from traditional pedagogy to a collaborative approach of using AI and generative AI tools as cognitive scaffolding. In addition, although the use of AI-based tools such as virtual labs and intelligent tutoring systems (ITS) is currently being employed to improve student engagement in the classroom, their successful

implementation is hampered by issues such as lack of AI literacy among teachers, and low levels of teacher preparedness for implementing this type of technology. The findings of the thematic analysis identified multiple different types of technical/ pedagogical / ethical challenges to using AI in science education, including (i) inaccuracies in the scientific method, (ii) algorithmic bias, and (iii) cognitive offloading. To overcome these challenges, there must be a restructuring of teacher preparation programs to include training on how to use generative AI tools for developing new prompts and developing ethical frameworks, such as AI know Sense. Educators will also need to be prepared to transition from being a traditional instructor to becoming a designer of inquiry-based pedagogical learning environments that employ the use of AI to facilitate discovery through critical thinking. To determine how AI affects students over long periods, future studies must be planned as longitudinal studies. Researchers also call for the creation of hybrid ecosystems that combine LLMs with simulations and AR in order to help educators connect what they are capable of doing with technology versus what is actually possible within their physical classrooms. The success of this goal of providing every child access to high-quality, equitable, and ethical science education relies heavily on the presence of standardized governance and collaboration between higher education institutions and government agencies to protect academic integrity, promote the scientific literacy of all students, and create opportunities for collaboration among educators.

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