

Personalised learning and artificial intelligence in science education: current state and future perspectives

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Abstract. This paper presents a comprehensive examination of the integration of artificial intelligence (AI) in science education and its impact on personalised learning. The research explores current applications, challenges, and future perspectives of AI technologies in educational settings. Through a systematic literature review, we identify the advantages of AI, such as enhanced individualised instruction, data-informed insights, and increased student engagement. The study combines quantitative and qualitative analyses, case studies, expert interviews, and technology assessments to offer a multidimensional understanding of AI's role in personalising science education. Despite the potential benefits, the research highlights barriers, including financial costs, infrastructure requirements, data privacy, and the need for teacher training. The future of AI in education suggests a trajectory towards advanced personalisation capabilities through adaptable learning systems, virtual tutors, and immersive learning environments. We underscore the importance of addressing the identified challenges to fully realise the transformative power of AI in science education. The findings illustrate that, with thoughtful implementation, AI holds promise for tailoring science learning experiences, making them more effective, inclusive, and engaging for students of varied needs and abilities.

Keywords: artificial intelligence, science education, personalised learning, intelligent tutoring systems, educational technology, systematic literature review, learner engagement

1. Introduction

Technology is playing an increasingly significant role in our daily lives, with artificial intelligence (AI) technology being a particularly noteworthy development. This technological advancement has had a profound influence on various sectors such as communication, education, healthcare, industry, and transportation [18, 62, 65].

AI is a branch of science that dates back to the mid-20th century and primarily focuses on the ability of computers to perform tasks similar to human intelligence [6]. Alan Turing's proposal of the Turing Test in 1950 and the popularisation of the term 'artificial intelligence' by John McCarthy are considered the starting points of AI research. In its early years, symbolic logic and natural language processing were the main focus [6]. Despite a period of disappointment in the 1980s, AI research was revived with the rise of statistical approaches like machine learning and

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deep learning. Today, AI has made significant advancements in areas such as speech recognition, image processing, automation, healthcare, transportation, and many more [42, 44].

In today's rapidly evolving digital landscape, numerous studies have indicated that the advent of AI and the widespread incorporation of technology are precipitating significant transformations within the field of education [2, 56]. The integration of modern educational technologies, particularly AI, has revolutionised teaching methods, learning approaches, and the overall education industry [5].

AI is a powerful tool that has the potential to significantly enhance and personalise the learning experience for students [8, 29, 66]. It can analyse vast amounts of data, identify patterns, and provide personalised recommendations and feedback to individual learners [22, 23, 36].

AI, as a groundbreaking technology, has the potential to revolutionise and personalise the learning experience for students [8, 29]. By integrating AI into education, we can unlock new possibilities for educational development and create innovative models of teaching. The utilisation of AI in various countries demonstrates a growing demand for training and platform construction in AI education [64]. This emerging field of AI education encompasses diverse technologies, personalised instruction methods, and intelligent student assessment techniques. As we explore the transformative effects of AI on education, it is crucial to consider its future implications and adapt our approach accordingly to ensure a successful integration of AI in the education sector.

The research aims to provide a more holistic understanding of AI's role in science education. Thus, it will provide valuable information for policymakers and technology developers to integrate AI more effectively in science classes and potentially provide the academic knowledge needed for this integration.

The research also provides support for creating improved learning environments for students. It offers a broad perspective grounded in current practices while exploring future potentials, addressing a temporal gap in the literature by connecting present realities with prospective advancements. This forward-looking viewpoint is essential in the rapidly evolving field of AI in education. The educational landscape is undergoing profound transformations through the integration of diverse technological advancements. This process of change will persist with the incorporation of AI. This research endeavours to provide a more nuanced and holistic understanding of the role of AI in personalised science education while also addressing existing knowledge gaps pertaining to its practical applications, challenges, and future trajectories.

The research questions of this study include the following:

- RQ1. How is AI transforming personalised learning in science education?
- RQ2. How can AI assist teachers in tailoring education to improve individual student outcomes in science?
- RQ3. What are the main obstacles involved in integrating AI into science education?
- RQ4. What future advancements in AI and machine learning could further personalise and enhance learning in science education?

2. Method

Research has been conducted based on research questions.

Data sources and search strategy: peer-reviewed academic journals, conference papers, and educational technology reports were systematically reviewed. Key databases included WoS, IEEE Xplore, ERIC, Scopus, and Google Scholar. The search was conducted using a combination of keywords, such as “AI in education”, “personalised science education”, and “intelligent tutoring systems”.

Inclusion and exclusion criteria: literature from the past ten years were reviewed to reflect recent developments. Studies were selected based on their relevance to AI applications in science teaching and learning. Non-empirical articles, articles not in English, and those unrelated to AI were excluded.

The data shows (table 1 and table 2) that scientific articles are the predominant publication type, and AI applications in education are the most common subject area among the references.

Table 1

Distribution by publication type.

Publication type	Frequency	Percentage
Scientific articles	64	87.67%
Conference papers	4	5.48%
Websites/online resources	3	4.11%
Book chapters	1	1.37%
Reports	1	1.37%
Total	73	100%

Table 2

Distribution by subject area (main themes).

Subject area (main theme)	Frequency	Percentage
AI applications in education	25	34.25%
Personalised learning	12	16.44%
Intelligent learning environments	9	12.33%
AI in higher education	8	10.96%
AI in K-12 education	7	9.59%
Teacher education and AI	5	6.85%
AI and learning analytics	4	5.48%
AI in medical and health education	3	4.11%
Total	73	100%

According to the data presented in table 2, the review encompassed a total of 73 studies, indicating that research on the integration of AI in the educational domain has been undertaken across a broad spectrum. However, the findings suggest a particular emphasis on exploring the general applications and personalised learning approaches facilitated by these technologies.

The VOSviewer network analysis map provides a comprehensive synthesis of the study’s key findings and conceptual framework (figure 1). Based on the sources utilised, the map illustrates the temporal progression of concepts and research in the domain of educational sciences in-

tersecting with AI. The centrally positioned “artificial intelligence” node underscores the focal point of the investigation, with its numerous interconnections highlighting the wide-ranging influence of AI within the field of education. Prominent nodes such as “education”, “machine learning”, and “deep learning” denote the primary research foci in this area. The colour-coded schema reflects the temporal significance and development of concepts from 2020 to 2023, with older concepts depicted by purple and blue hues and newer emerging areas indicated by green and yellow tones. This temporal mapping highlights the growing prominence of concepts like “personalised e-learning”, “educational data mining”, and “adaptation models”. Furthermore, the network map elucidates the application of AI in STEM and higher education, with nodes depicting the technological underpinnings of personalised learning strategies, including recommender systems and knowledge-tracing models.

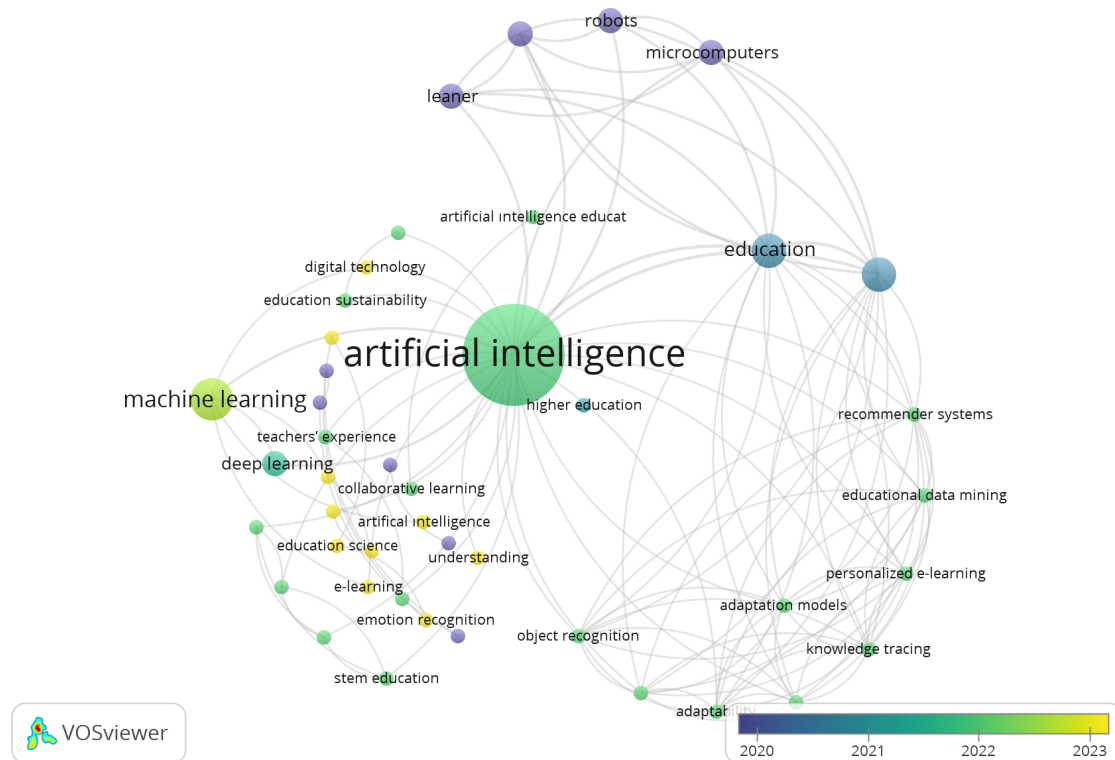


Figure 1: VOSviewer network visualisation.

Note: In order to analyse with VOSviewer, the appropriate file extension and data information must be complete. Sources that do not meet this criterion are not included in the analysis.

3. Results

Various studies have been conducted in the field of AI and individualised learning. Some of the latest studies in the field of science education are as follows:

- (1) This study proposes the use of embedded devices and AI solutions to analyse classroom behaviours and improve teaching quality [40]. The findings suggest that incorporating smart devices in science classes can enhance student satisfaction and instructional effectiveness. However, the research also identifies limitations and suggests potential experiments for future studies. Further optimisation of algorithms and providing more statistical information on instruction are areas for improvement in this study.
- (2) This article examines how AI has reshaped the education model [53]. The authors have emphasised that the integration of AI and educational technologies offers the potential for personalised education and intelligent student assessment. They have noted that the diversity of various technologies characterises AI education, but it is mentioned that this technology has not matured enough and is a problem that requires a solution. It has been revealed that there are specific trends in AI and education integration studies in South Korea, Japan, the United States, Russia, Germany, and China.
- (3) This study presents a bibliometric analysis of the literature on AI and manufacturing published between 1979 and 2021 [31]. It has been determined that the countries with the highest overall publication rates in AI are China, the United States, and the United Kingdom, respectively. During this period, China has become the most active country, with its universities being the top publishers.
- (4) This study has provided a systematic review of the application of AI technologies to STEM education between 2011 and 2021 [72]. The aim is to identify both the categories of AI elements integrated into the AI-STEM system and the characteristics of other system elements (information, subject, environment, environmental element), as well as to determine the distribution of AI within these elements, and to assess the impact of AI on STEM education. As a result of the study, the relationship between AI technology and STEM education is defined through six main AI applications: learning prediction, intelligent tutoring systems, student behaviour detection, automation, educational robots, and others.
- (5) This article systematically examines a series of studies to uncover how AI technologies are utilised in Latin American higher education institutions [59]. This systematic review highlights the challenges and potential of implementing AI in higher education institutions in Latin America. It has been revealed that AI technologies are being used in various ways, but adoption is still slower compared to other fields. It has been observed that AI is used in five main ways, including predictive models, smart analytics, assistive technology, automatic content analysis, and image analytics. The need to increase awareness of the potential benefits of AI technologies in solving higher education issues, such as improving student performance, simplifying the work of teachers, and supporting university services, has been emphasised.
- (6) The article investigates the influence of AI on teaching and learning in higher education [51]. The research underscores the significance of viewing technology as a tool to augment human cognition and enhance the educational experience. However, it raises concerns about reducing education to mere protocols focused solely on content delivery, regulation, and evaluation. The article emphasises the integration of AI with human abilities and stresses the importance of not relying solely on technology for education. It presents various AI technologies that can function as virtual teacher's assistants in online learning, performing tasks such as organising information, enhancing student learning, monitoring

progress, assessing performance, and managing resources. One example discussed is the use of “Teacherbots”.

- (7) The purpose of this study is to develop an AI-supported predictive model taking into account learning processes and teaching data [30]. The model is used to predict the academic performance of students in online engineering courses. Additionally, the research aims to address existing challenges in areas such as identifying learning data and analysing data. The research results show that the determinants of academic performance are information acquisition, in-class participation, and teaching performance. The model has successfully characterised students’ learning data during a specific instructional process and has been validated on another online course that uses the same pedagogy and technology. The research findings indicate that the genetic programming model provides acceptable predictive performance compared to other AI methods.
- (8) The primary objective of this study was to assess the knowledge and beliefs of in-service K-12 teachers regarding AI [3]. Furthermore, it aimed to investigate their attitudes towards integrating AI into educational practice. The findings indicated that while most teachers possessed an accurate understanding of AI, there were also prevalent misconceptions, such as viewing AI as expensive or capable of independent learning. Overall, teachers displayed a positive disposition towards utilising AI in classrooms, with only a minority expressing scepticism. Additionally, the majority believed that students should have a foundational understanding of AI but expressed uncertainty or concern regarding its ethical implications.
- (9) The purpose of this study was to examine the factors that contribute to the successful implementation of AI in science classrooms [47]. It also aimed to determine the relationship between predictors of approval for using AI and investigate any potential differences based on gender, age, and residence status among teachers. The findings revealed that science teachers generally approved of using AI, regardless of their demographic characteristics.
- (10) A research study aimed to explore how popular science activities affect the progress of AI, specifically when it comes to having or lacking teacher assistance [70]. The findings indicate that such activities can contribute to the cognitive development of AI concepts but may necessitate additional time for skill enhancement. Moreover, it was observed that AI science education initiatives yield distinct learning outcomes depending on whether there is teacher support in place. While teacher-supported activities have the potential to improve student’s learning outcomes, they may also foster excessive reliance on teachers by students.
- (11) The purpose of this study is to explore the attitudes and readiness of medical students at Kuwait University’s Faculty of Medicine towards incorporating AI in their education [7]. The findings indicate that a majority of students hold a positive perception towards AI and are open to embracing its integration into their medical training. Furthermore, many students believe that incorporating AI into their education can effectively prepare them for real-life clinical scenarios.
- (12) The study aimed to explore the use of AI in supporting science teachers’ abilities to design integrated science lessons that foster high-level thinking skills [25]. The implementation of this program has effectively enhanced science teachers’ knowledge and skills in lesson planning, specifically within the framework of integrated science learning. All participants

found the recommendations suggested by AI to be innovative and valuable additions to their teaching practices.

- (13) In this study, a bibliometric analysis was conducted to examine articles on the use of AI technologies in education [32]. The findings revealed that there is a strong presence of research on AI technology in international literature, particularly focusing on topics like student dropout rates and the use of chatbots. Furthermore, recent years have seen an increase in popularity for subjects such as participation, collaborative learning, natural language processing, e-learning, artificial neural networks, and intelligent educational systems.
- (14) The objective of this research was to examine the proficiency of African K-12 students in AI education [60]. Specifically, it aimed to identify the key skills that are most important for middle and high school students in Nigeria when it comes to AI education. The study emphasised the importance of incorporating tailored activities and tasks into the curriculum to enhance these skills. Additionally, there was an emphasis on integrating ethical considerations more prominently within the educational program in order to foster a deeper understanding of AI and cognitive abilities among students.

After a general examination of the research findings on AI and personalised learning, some key points emerge:

- AI application in education is a growing field, with varying implementation levels across different countries and disciplines.
- AI's potential uses are broad and include areas like predictive modelling, behaviour and sentiment analysis, enhancing teaching quality and student performance, and providing personalised education.
- The integration of AI in education is challenging. Some of the issues identified are technology maturity, slow adoption in specific regions, and the need for continuous optimisation of AI algorithms.
- Some works underscore the importance of AI complementing rather than replacing human involvement in education, not to reduce education to mere technological protocols. While AI boasts vast potential, its successful implementation requires careful consideration of optimisation and human-AI interaction. Its adoption needs to be further pushed and standardised to unleash its full potential in science education.

3.1. RQ1. How is AI transforming personalised learning in science education?

AI plays a crucial role in science education, revolutionising the way students learn and achieve academic success. By analysing individual students' learning pace, style, and abilities, AI provides personalised learning experiences. This enables the creation of customised learning paths tailored to meet each student's unique needs and capabilities, ultimately optimising their educational journey. Current applications of AI in science education include personalised learning platforms (1), intelligent tutoring systems (2), virtual reality simulations (3), data analysis and prediction models (4), and adaptive assessment tools (5) that provide personalised feedback and recommendations to students [8, 50, 58].

- (1) *Personalised learning platforms* use AI algorithms to adapt instruction and content to meet the individual needs and preferences of each student. These platforms can provide customised resources, adaptive practice exercises, and targeted feedback to support the learning process [13, 45].

Personalised learning platforms utilise AI algorithms to analyse individual student needs and preferences, resulting in tailored instruction and content. These platforms offer personalised resources, adaptive practice exercises, and specific feedback to optimise the learning experience for each student. The integration of AI algorithms within these platforms facilitates the personalisation of instruction and learning resources, aligning them with the unique needs and preferred learning styles of each student [54]. This, in turn, ensures that students receive bespoke content that caters to their requirements, ultimately fostering a more effective and engaging educational experience.

One pivotal feature that characterises these platforms is their provision of Adaptive Content Delivery (ACD) [24, 39]. This implies that students are exposed to materials that align with their current level of understanding and their favoured mode of learning. This dynamic adaptation safeguards students from feeling overwhelmed by content that is overly advanced or disengaged by overly basic material. The AI algorithms employed in these platforms play a central role by collating and scrutinising extensive data concerning each student's educational history, test scores, and interactions within the platform. This information empowers the platform to construct comprehensive profiles of individual students, enabling a deeper comprehension of their strengths, weaknesses, and preferred learning modalities. Continuous Feedback and Assessment (CFA) constitute integral components of these platforms. Students promptly receive feedback on their assignments and assessments, including detailed explanations for incorrect responses and recommendations for improvement [30, 69]. Regular assessments serve to monitor a student's progression and to identify areas where supplementary assistance may be necessary.

Furthermore, these platforms cater to Varied Learning Styles (VLS) by presenting content in formats that resonate with each student's distinct preferences [14, 15]. Visual learners may have access to videos and infographics, while auditory learners might be provided with audio explanations. This approach ensures that the educational material effectively engages all students. Flexibility is another pivotal attribute of these platforms [14]. They grant students the liberty to access educational materials at their convenience, rendering them suitable for diverse learning environments, ranging from traditional classrooms to online settings. Educators also benefit significantly from these platforms as they gain invaluable Insights into student performance and needs [26, 67]. This data-driven methodology enables instructors to adapt their teaching strategies and provide targeted support to individual students, fostering a collaborative and enriched learning environment [13, 72].

- (2) *Intelligent tutoring systems (ITS)* showcases a significant advancement in education technology. They utilise AI to provide personalised learning experiences for students. Acting as virtual tutors, these systems offer individualised instruction and immediate feedback to learners [19].

Key components of ITS include advanced AI algorithms that constantly assess and analyse multiple factors such as a student's existing knowledge, speed of learning, strengths, and

weaknesses [49]. This thorough examination enables ITS to generate detailed learner profiles that reveal essential insights into each student's specific educational requirements. One of the key characteristics of ITS is its capacity to adjust and modify learning materials in response to a student's progression. This ensures that as students continue on their educational path, the system adapts the content according to their current knowledge and goals. If a student demonstrates proficiency in a specific area, the ITS can provide more advanced material to keep them engaged and challenged. In contrast, when students face challenges, the system can provide extra assistance and alternative explanations, promoting a more thorough understanding of the content.

Moreover, ITS are specifically developed to provide prompt and helpful feedback to students as they interact with their learning materials. This feedback goes beyond simply acknowledging correct or incorrect answers; it includes in-depth explanations for mistakes and actionable recommendations for improvement. ITS offers continuous assessments to track students' progress and maintain their academic trajectory. They represent the fusion of AI with education, providing personalised instruction and feedback that can significantly impact the educational landscape. By leveraging AI technology, ITS deliver adaptable lessons tailored to each student's needs, ultimately enhancing engagement and effectiveness in learning [17, 38].

(3) *Virtual reality simulations* (VRS) are another promising tool in the realm of science education [21, 68]. These simulations create immersive and interactive learning environments that allow students to explore scientific concepts and phenomena in a hands-on manner. With virtual reality simulations, students can manipulate objects, conduct experiments, and observe outcomes in a virtual setting that closely resembles the real world [9, 51]. This experiential approach to learning promotes deeper understanding and engagement, as students can actively interact with the content.

Integration of AI in science education, specifically through virtual reality simulations, represents a modern advancement. This novel approach aims to improve the learning process by leveraging AI-powered virtual reality technology.

ITS utilise AI techniques to create computer programs that enhance learning by providing interactive virtual reality simulations. These simulations effectively combine theoretical concepts with real-world applications, offering students an immersive and engaging learning experience that is particularly beneficial for science education.

AI has had a profound influence on these simulations by producing adaptable and reactive learning environments. By employing machine learning algorithms, AI is able to assess the progress of students and adjust the difficulty or content of the simulation accordingly. This customisation enables a personalised educational experience that caters to individual learning needs and enhances scientific knowledge acquisition. Through the integration of AI into science education via virtual reality simulations, students can participate in immersive and interactive learning experiences that deepen their understanding of scientific concepts [39, 53, 71].

Additionally, AI enables the development of immersive and dynamic simulations that replicate intricate real-life situations [27]. This provides students with the opportunity to explore, make errors, and gain knowledge from their interactions in a secure virtual setting. Consequently, this not only enhances understanding but also fosters the growth of problem-solving abilities and critical thinking skills, which are indispensable for scientific endeavours [5, 34].

- (4) *Data analysis and prediction models.* Currently, the incorporation of AI in science education has become a significant focus for educators and researchers [24, 70]. The goal is to improve students' understanding of scientific concepts and develop 21st-century skills through the utilisation of modern educational technologies. One rapidly growing technology in the field of education is AI, which has brought about changes in teaching methods, learning processes, campus environments, curricula, and the entire education industry.

In the field of science education, AI plays a critical role in data analysis by efficiently processing large datasets. This enables students to work with real-world data and engage in authentic scientific investigations. With the help of AI-driven tools and software, learners can confidently explore complex scientific data, identify patterns, and make insightful conclusions [43, 59]. By developing these skills, students not only enhance their understanding of data but also gain valuable analytical abilities that are vital for contemporary scientific research.

Moreover, the incorporation of modern educational technologies in the teaching of science is a topic that has garnered significant attention from educators and researchers. The aim is to enhance students' understanding of scientific concepts and equip them with 21st-century skills to improve the learning process and its outcomes [25, 63, 72]. AI has emerged as one of the rapidly growing technologies in education, leading to changes in schools, teaching methods, learning approaches, campus environment, curricula, and the entire education industry [52, 61].

- (5) *Adaptive assessment tools* is another area where AI is making a significant impact in science education is adaptive assessment tools [46, 73]. These tools utilise AI algorithms to analyse students' performance and provide personalised feedback, allowing educators to gain insights into individual strengths and weaknesses [8]. Furthermore, AI-powered adaptive assessment tools in science education enable personalised learning experiences for students. These tools can adjust the difficulty level of questions based on a student's performance, ensuring that they are appropriately challenged and supported in their scientific journey [68, 70].

One of the most significant AI advancements in 2024 has been the development of updated models capable of reasoning across audio, text, and visual data [20, 37]. This introduces innovations such as real-time conversation, emotional state sensing, and live stream interpretation [37, 48]. These innovations make it possible to account for each individual's emotional state in the learning process. Educators will be able to understand students' emotional and engagement levels, and when a student experiences disappointment, waning interest, or overwhelm, the AI system can detect these situations and provide educators the opportunity for timely intervention. Additionally, learners can continue their learning process more effectively with AI-powered feedback, independent of the teacher and learning environment.

3.2. RQ2. How can AI assist teachers in tailoring education to improve individual student outcomes in science?

Personalised learning contributes to the improvement of science education by tailoring the learning experience to meet the individual needs and preferences of students [33]. This approach recognises that every student has unique strengths, weaknesses, learning styles, and interests.

By leveraging personalised learning strategies, teachers can create a more engaging and relevant learning environment for students. Personalised learning, in combination with the integration of AI, contributes significantly to the improvement of science education in several ways [4]:

- (1) *Tailored instruction*: personalised learning leverages AI algorithms to evaluate the unique strengths and areas for growth of each student [23]. This enables educators to design customised educational journeys that cater to individual students' requirements. In the context of science education, where students often possess diverse levels of comprehension and interests, this approach ensures that every learner receives tailored challenges and necessary assistance in their academic pursuits [57].
- (2) *Engagement*: AI-driven personalised learning uses interactive and multimedia components to enhance student engagement [72]. This may involve the use of simulations, virtual labs, and gamified content, which can make science education more enjoyable and relatable for students [39].
- (3) *Adaptive assessment*: AI can continuously track and assess a student's performance, allowing for personalised adjustments in the complexity of learning materials and assignments [13]. This ensures that students are provided with content suited to their individual needs, preventing them from feeling overwhelmed by advanced topics or disengaged by simplistic material. By tailoring their educational experience, AI promotes sustained engagement and motivation in students' learning journey [35].
- (4) *Instant feedback*: AI can offer instant feedback to students regarding their performance [1, 12]. This prompt response assists students in comprehending their errors and rectifying them immediately, particularly in scientific subjects where accuracy and precision play a vital role.
- (5) *Efficiency*: with the advancement of AI, personalised learning has become achievable. AI plays a significant role in various aspects of education, such as tutoring, assessment, and teaching optimisation, ultimately leading to improved efficiency in teaching and enhanced learning experiences for students [28, 58]. AI has emerged as a crucial factor in the development of educational technology, promoting innovation in education and teaching methods [16]. The impact of information technology extends beyond just science and technology but also holds immense significance within our changing times.

3.3. RQ3. What are the main obstacles involved in integrating AI into science education, and how can they be overcome?

One of the challenges in implementing AI in science education is the initial cost and infrastructure required to integrate these technologies into educational systems [47, 72]. This includes the need for updated hardware, software, and internet connectivity, which may not be readily available in all educational settings. The implementation of AI technologies in science education necessitates a financial commitment. This involves the acquisition of AI software, hardware, and associated tools. The expenses can be significant, posing a challenge for numerous educational institutions, particularly those with restricted budgets. To effectively utilise AI in education, educational institutions need to have a robust infrastructure in place [14]. This may involve upgrading existing systems and investing in powerful computers or servers that can efficiently

run AI algorithms. By ensuring the necessary infrastructure, institutions can fully harness the benefits of AI applications in education. Implementing AI in education becomes a challenge in areas where internet access is limited or unreliable, as AI often relies on cloud-based services for data processing and storage. Access to reliable and high-speed internet connectivity is essential for effectively using these services.

Another challenge is the need for high-quality and reliable data to train AI algorithms [43, 66]. AI implementation in education often involves the collection and analysis of student data. It is crucial to prioritise the privacy and security of this data, which may require additional resources and expenses for implementing necessary safeguards. The ethical implications of using AI in education, especially in terms of data collection, student privacy, and algorithm bias, are also significant challenges that need to be addressed [10].

Furthermore, there may be a lack of proper training and professional development for teachers to effectively utilise AI in science education [47]. Teachers may require specialised training to understand how to integrate AI technologies into their teaching practices and curriculum. Some educators may need more training to utilise AI technologies in their instructional practice effectively. The complexities associated with AI tools and applications might be unfamiliar territory for teachers, hindering their ability to seamlessly incorporate them into their teaching strategies [3, 11]. Continuing professional development is vital for teachers to stay current with the latest teaching techniques and technologies.

However, when it comes to integrating AI into science education, there may be limited opportunities for teachers to acquire the necessary skills and knowledge needed to incorporate AI tools in their instructional approaches effectively. Teachers who lack adequate training and professional development may face challenges in effectively utilising AI in the classroom [41, 47]. Without proper knowledge of how to incorporate AI applications into their science lessons, they may not be able to maximise its potential benefits, resulting in less-than-optimal outcomes for students. Without adequate training and professional development, there is a risk of overlooking the potential advantages of AI in education, including personalised learning, data-driven insights, and increased student engagement [55].

Overall, while implementing AI in science education presents challenges and limitations, the potential benefits and opportunities it offers for personalised learning and instructional effectiveness must be addressed.

3.4. RQ4. What future advancements in AI and machine learning could further personalise and enhance learning in science education?

The future of integrating AI and personalised learning in science education holds great potential. Advancements in AI technologies and the increased availability of AI tools and platforms will likely provide more opportunities for teachers to incorporate personalised learning experiences in their science classrooms. Additionally, ongoing research and development in AI algorithms and machine learning models will contribute to more accurate and adaptive personalised learning experiences for students. Moreover, as teachers become more familiar with AI tools and gain the necessary knowledge and skills to use them effectively, the integration of AI in science education is expected to become more seamless and widespread. The integration of AI and personalised learning in science education holds significant promise for the future, offering

various perspectives and potential developments:

- AI-powered systems will become increasingly adept at customising content delivery to suit the needs of individual students. By analysing a student's progress, learning style, and preferences, these systems can provide personalised lessons and resources, resulting in more engaging and effective science education.
- AI technology will have an increased impact on assessing student performance. It will offer real-time feedback on assignments and quizzes, identifying areas of difficulty for students and providing targeted guidance for improvement.
- Personalised learning systems will generate individualised pathways for each student, considering their previous knowledge, interests, and objectives. These pathways will accommodate a student's science proficiency to enable them to advance at their preferred speed while addressing areas of strength and weakness.
- To improve science education, AI can leverage predictive analytics to identify students who may be at risk of falling behind. This enables teachers and administrators to intervene early on and offer extra support to those students in need.
- AI-driven virtual tutors will continue to advance in sophistication, providing natural language interactions, personalisation, and extensive subject knowledge in the field of science. These tutors will be accessible around the clock, offering assistance with homework assignments and answering any queries students may have.
- The advancement of AI has led to the development of intelligent virtual tutors. These AI-powered tutors are becoming increasingly sophisticated, providing natural language interactions and personalised assistance in various subjects, including science. With their deep subject matter expertise, these virtual tutors will be available round the clock to help with homework assignments and answer students' questions.
- The integration of AI in science education will lead to the development of immersive and gamified learning experiences. Through virtual reality and augmented reality tools, students will have the opportunity to engage in hands-on activities that enhance their understanding of scientific concepts.
- AI can be used to ensure that science education is accessible for students with varying needs and abilities, promoting inclusivity. It can customise content for students with learning disabilities and offer additional challenges for advanced learners.
- AI tools can provide valuable support to teachers, enabling them to personalise learning experiences for their students. These tools can assist in resource selection, monitoring student progress, and tailoring teaching approaches to meet individual needs effectively.
- With the integration of AI-powered science education platforms, individuals will have access to continuous learning and skill development opportunities in the field of sciences. This is especially important in a rapidly evolving technological environment where staying updated is essential.

4. Conclusions

This study critically examines the deployment of AI in science education, with an emphasis on personalised learning. The findings underscore AI's potential to revolutionise science education

by providing tailored content that caters to individual student profiles. AI-driven systems have shown proficiency in adapting learning materials, delivering personalised lessons, and furnishing real-time feedback, which collectively contribute to an enriched learning experience. For instance, AI's predictive analytics can identify students at risk, enabling timely intervention and support tailored to individual needs.

However, implementing AI within educational frameworks faces considerable challenges. The document points out that significant initial investments, infrastructural requirements, data quality, privacy, and the need for specialised teacher training are vital issues that must be addressed. Institutions must be ready to invest in both technological and human capital to harness AI's potential fully.

Future developments in AI hold the promise of further personalising learning experiences in science education. Advances in natural language processing and adaptive learning can mimic human-like interactions and anticipate student needs with greater accuracy. Virtual reality and augmented reality tools are expected to provide immersive and interactive learning experiences that could transform the traditional classroom.

Ultimately, the integration of AI in science education facilitates a transformative shift towards more effective, inclusive, and continuously adaptive learning opportunities. However, realising these benefits hinges upon overcoming the outlined challenges, particularly ensuring ethical deployment and equitable access to these emerging technologies. As we move forward, it will be critical to continuously evaluate the impact of AI on educational outcomes and address the barriers to its implementation.

5. Recommendations for future research

This study presented a comprehensive review of personalised learning and AI in Science Education and revealed key findings on the current state and future perspectives. The results obtained not only expanded the existing knowledge in the field but also revealed new research requirements. Based on the study's findings, this section presents a number of recommendations for future research.

Impact evaluation is an important issue in the integration of each new technology developed into the field of education. These evaluations, which are necessary for the effective use of technology for the purpose, depend on academic research. Two academic areas of study that are important for the integration of AI-based personalised learning systems into the field of education are student success and motivation. New studies can be conducted to evaluate the impact of AI technology in these two areas.

Unlike technologies previously integrated into the field of education, AI technology uses a lot of private data to support personalisation and individual learning and is critical. Therefore, new academic studies should be conducted to determine appropriate ethical standards in the use of technology.

Although the positive contribution potential of AI technology to the field of education is considered high compared to other technologies, the necessary impact analyses should be carried out by including long-term studies in order to implement the necessary policies for its integration into the education system and to organise the curriculum contents.

6. Declarations

Conflict of interest: None

Data availability: The data used in the study are different types of articles that answer the research questions. These articles, which are data, are included in the references list.

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