Comprehensive Review on Technology-Based Learning Using Artificial Intelligence for Science Subjects and Its Implications in Teaching and Learning

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ABSTRACT

Awareness of technological advancements in education is crucial to ensure that teaching and learning methods are more relevant and effective. Artificial intelligence (AI) is a new emerging technology in education, enabling computers to have human-like cognition. However, research on the effectiveness of AI technology in teaching and learning (TaL) science subjects is still limited. This literature review aims to identify trends, impacts, and challenges of AI implementation in science learning. The review employs a systematic review method consisting of four steps: framing research questions, searching for relevant articles or journals, reading and analyzing abstracts, and extracting information from the articles or journals. A total of 30 articles were reviewed in this study. The results of the review indicate that AI provides a positive effect on learning. A popular trend in the use of AI technology in science learning is chatbot from ChatGPT. The impact of applying AI in science education includes student motivation and engagement, understanding complex and abstract concepts, improving the quality of science education, personalized learning, and its use in assessment and testing. Challenges in the application of AI in science education include lack of teacher-student interaction, high dependence on AI technology, lack of teacher training, adaptation, and integration of AI technology in the curriculum, variations in accessibility and quality, and ethical challenges. AI has a great opportunity to be implemented in support of science learning, considering its impact and challenges. In general, AI has a significant influence on supporting better learning.

Keywords: Artificial Intelligence, Science Subject, Teaching Aids

INTRODUCTION

In this era of globalization, education plays a crucial role in developing students who are skilled, competent, and globally competitive, capable of facing the challenges of the Industrial Revolution 4.0. Education is a vital element in the process of growth and development for any nation [1]. One of the subjects emphasized in 21st-century learning is science [2]. The Malaysian Ministry of Education stresses the importance of Science in the Malaysian education system, aiming for a 60:40 ratio between Science and Arts subjects in the Malaysian Education Development Plan 2013–2025 (PPPM). This focus is because Science has become a key element in technological and social development and is a primary pillar for economic growth and public well-being, more so than in the past [3].

However, the performance in science subjects in Malaysia has seen a significant decline, raising concerns among educators. We can see this decline through international assessments such as Programme for International Student Assessment (PISA). PISA is an international test that help to measures literacy, mathematics, and science abilities of 15-year-olds student every three years. The assessment given by PISA focuses on student capability to apply knowledge, and skills in real-world content rather than rote memorization [4]. PISA plays a big role in global education, because it provides comprehensive information on knowledge assessment especially in science and provide survey data for schools, teachers, and parents to help them analyzing key factors affecting education in many countries [5]. According to the preliminary report of Malaysia's PISA 2022 result, we can see that the country's performance in scientific domain dropped by 4 points, from 489 in PISA 2018 to 485 in PISA 2022 [6].

One of the reasons for this decline is there have a lot of abstract concepts in science such as mechanical forces, which make it difficult for students to grasp these concepts effectively. After that, many teachers in schools still rely on conventional teaching method, such as "Chalk and Talk" that fail to engage students in learning science [7, 8]. One way to overcome this issue is by implementing Technology-Based Learning (TBL) to teach science. The use of technology to teach science subject can help teachers to attract students' interest and explain every abstract concept in science [9]. The integration of technology in science education aligns with Malaysia's emphasis on the "Digital Education Policy," which aims to create creative, innovative, efficient, and highly motivated educators and students [10]. Moreover, since the COVID-19 pandemic, the reliance on technology in education has surged dramatically, prompting many educational institutions to incorporate digital technology into their teaching processes [11]. This increased use of technology in education has led to more children today starting to use various technologies to enhance their learning achievements at a very young age [12]. Therefore, every school must implement digitization in the education process, especially in science subjects, by using electronic devices, platforms, and other technologies to improve the quality of learning [13].

Artificial Intelligence (AI) technology is one of the most notable technical advancements in education in the 21st century. AI technology allows computers to mimic human activities and perform tasks that typically require human intelligence [14]. The use of AI technology offers tremendous potential in addressing issues within traditional education systems, such as disparities in education quality and accessibility, limitations in learning resources, and more, through intelligent learning systems, automated assessments, and personalized learning [15]. Therefore, teachers in school must begin to focus on incorporating technology, especially AI technology, into education, particularly in science subjects, which are a key focus in Malaysia's educational system.

Various study results have implemented AI in learning. AI has been utilized to support practical and communicative learning. The variation in the results of the AI impact shows a variety of effects. To gain a comprehensive understanding and general conclusions about the impact of AI implementation on science learning, a thorough review of the results of previous studies is needed. It aims to investigate AI trends, impacts, and challenges. Thus, a comprehensive investigation in the literature review as the latest innovation and novelty is crucial to understanding the impact of AI on science learning.

OBJECTIVES OF THE STUDY

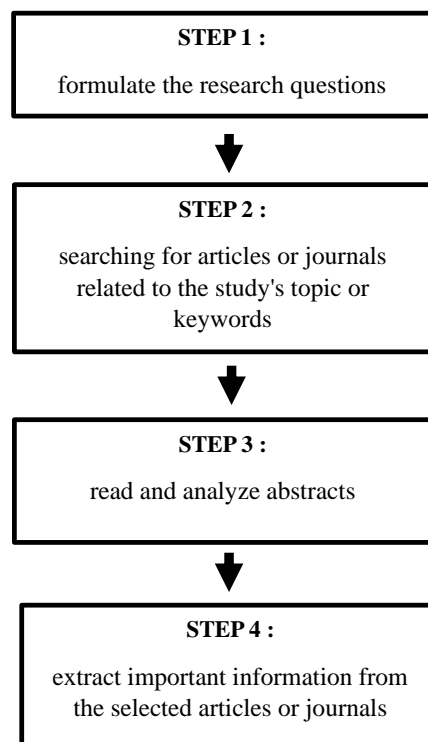Extensively, the objectives of this literature review are to:

i.   Identify the trends in the use of AI technology in science education.
ii. Identify the effects of using AI technology in science education.
iii. Identify the challenges faced in implementing AI technology in science education.

RESEARCH QUESTIONS

i.   What are the trends in the use of AI technology in science education?
ii. What are the effects of using AI technology in science education?
iii. What are the challenges faced in implementing AI technology in science education?

METHODOLOGY

The purpose of this literature review is to examine the effectiveness of using AI technology in science subjects. Various literature sources involving the use of AI technology in science education have been selected from several online sources, such as books and journals. In this study, searches were conducted through various websites such as Google Scholar, ProQuest, and Research Rabbit, as well as open-access journals related to the impact of AI technology in Science education. This study only includes sources from the last five years, specifically those published between 2018 and 2024, to ensure that the sources were still relevant. This study utilized the systematic literature review method outlined by Basu [16], which involves four main procedures. The procedures of the systematic literature review are presented in Figure 1.

STEP 1 :

formulate the research questions

⬇

STEP 2 :

searching for articles or journals related to the study's topic or keywords

⬇

STEP 3 :

read and analyze abstracts

⬇

STEP 4 :

extract important information from the selected articles or journals

Figure 1. The Four Procedures of the Systematic Literature Review Method by Basu [16]

Figure 1 shows four procedures for the systematic literature review. The first step is to formulate the research questions. The research questions were framed using the Population, Intervention, Comparison, and Outcome (PICO) framework [17]. The population refers to a group that was studied comprehensively and thoroughly in a research study, which can be classified by characteristics, such as age and gender [18]. The population for this study includes secondary school teachers and students involved in teaching and learning of science subjects. The intervention used in this study was the application of AI technology in science education, such as educational chatbots and virtual laboratories. The comparison made in this study was between teaching methods using AI and conventional teaching methods. The expected outcomes of this study are that the use of AI technology shows a significant improvement in science subjects, motivation, the classroom engagement, and understanding abstract concepts compared to the conventional teaching methods.

The second step was searching for articles that are related to the study's topic or keywords. This step conducted by using the database from Google Scholar, ProQuest, Zendy, and other open-access journals. AI technology such as Research Rabbit AI and Perplexity were also used in this study to assist in finding relevant articles. The third step was to read and analyze all of the selected articles to ensure that they relate or are relevant to the topic. The selected articles were stored in a special folder. The last step used in this study was to extract crucial data in a tabular form from the chosen publications to help with writing. After running all the steps, the researchers wrote a report based on the study's findings and subsequently publish the study.

RESULTS AND DISCUSSION

WHAT ARE THE TRENDS IN THE USE OF AI TECHNOLOGY IN SCIENCE EDUCATION?

A new age in science education has begun with the advent of AI technologies in recent years. Initially, AI was implemented in the form of computer technology, which then evolved into intelligent, web-based educational systems, and eventually transitioned into embedded computer systems like humanoid robots and web-based chatbots designed to perform teaching functions independently or alongside teachers [19]. In science education, AI technology can be implemented in various forms of learning.

One of AI technologies frequently used in science education is the application of chatbots for learning support, such as ChatGPT. ChatGPT is a chatbot developed by OpenAI that uses language and thinking similar to humans [20]. Based on the input given, ChatGPT is a generative AI that creates human-like text [21]. Science teachers in schools can use ChatGPT to assist them in creating a good daily lesson plan (DLP). The lesson plan created by ChatGPT suggests various inclusive activities that enhance critical thinking and maintain human creativity during the teaching and learning sessions [22]. Additionally, ChatGPT can help students gather information from various sources, improve their language proficiency, save time by enabling more effective learning, and provide support for their studies [23]. Furthermore, ChatGPT can help boost student motivation to learn more effectively compared to conventional teaching methods. This is because, ChatGPT can help students by providing study materials, making them more enthusiastic to learn and achieve excellent results in science subjects [24]. ChatGPT also has the potential to increase student engagement in the classroom. The students who are proficient in using ChatGPT tend to be more actively involved in the classroom compared to less proficient students. Good student engagement during learning sessions can positively impact their understanding of a particular field or topic they are studying [25].

Virtual labs can also be monitored by AI technology. The virtual labs help you perform experiments at any time. This makes it more convenient for remote students or those unable to visit labs. The cost-impact of using virtual labs can be especially smaller when taking into consideration potential incidents or accidents that will occur within the physical lab [26]. It also enables the students to know in real-time, which helps in the identification of errors and further corrects them at that moment. However, receiving immediate feedback can result in the most rapid growth of a student and a more long-term understanding of studied subjects [27]. They have the possibility of learning from multiple resources in one place because there are a host of support tools available in these virtual labs. It enables students to learn more deeply, and it provides tailored learning experiences that cater for the different needs of individual students [28]. However, the use

of virtual labs is restricted in regions with good internet connections and sufficient devices. The technical problems seen included (a) accessibility (internet connectivity) and (b) inaccessibility (software crashes), all of which disturbed the process of learning [29].

WHAT ARE THE EFFECTS OF USING AI TECHNOLOGY IN SCIENCE EDUCATION?

AI technology has recently been introduced into the education sector, especially in higher education, due to its high potential to enhance student achievement. AI in education refers to the use of AI technology to improve the learning experience, personalize learning, and increase teaching efficiency [30]. AI technology has emerged as a significant tool in science education in Malaysia. Various past studies have demonstrated the impact of implementing AI technology in science education. The impact of AI implementation on science learning is presented in Table 1.

Table 1. Findings on the Impact of AI Technology in Science Education

No.	Source	Impact	Finding
1.	[31] (Wu, & Yang, 2022)	Motivation and Student Engagement	The use of AI technology can enhance students' motivation to learn science subjects.
2.	[32] (Iyamuremye & Ndihokubwayo, 2024)	Motivation and Student Engagement	A thematic analysis of focus group discussions revealed that the use of generative AI, such as ChatGPT, can enhance student engagement and interactivity in learning. Students reported feeling more involved and active in the learning process.
3.	[33] (Hallal, Hamdan & Tlais, 2023)	Motivation and Student Engagement	AI technology can provide an interactive learning experience where students can interact with AI technologies such as chatbots for immediate feedback and assistance in completing their tasks.
4.	[34] (West et al., 2023)	Understanding Complex and Abstract Concepts	Generative AI, such as ChatGPT version 3.5, is capable of producing clear and error-free scientific reports with accurate information.
5.	[35] (Wardat et al., 2023)	Understanding Complex and Abstract Concepts	Generative AI, such as ChatGPT, helps overcome language barriers and provides explanations along with examples to help clarify complex concepts.
6.	[36] (Suhonen, 2024)	Understanding Complex and Abstract Concepts	AI technology is capable of providing personalized support, helping students understand complex concepts in science subjects, and enhancing their problem-solving skills.
7.	[37] (Erduran & Levrini, 2024)	Understanding Complex and Abstract Concepts	Teachers and students can use AI technology as a tool to solve scientific problems.

8.	[38] (Selvam, 2024)	Enhancing the Quality of Science Education	It provides students with the opportunity to explore science in a unique way by combining human expertise and AI in their learning process.
9.	[39] (Ezquerra, Agen, Rodríguez Arteche, & Ezquerra-Romano, 2022)	Enhancing the Quality of Science Education	The use of AI in researching emotions and behaviour in science education can provide deeper insights into the student learning process.
10.	[40] (Sanchez-Gonzalez & Terrell, 2023)	Enhancing the Quality of Science Education	Science learning that combines voice-over and AI is more effective compared to conventional learning methods.
11.	[41] (Cooper & Tang, 2024)	Enhancing the Quality of Science Education	Generative AI, such as DALL-E 3, can help generate images that enhance students' understanding in science subjects.
12.	[42] (A'ini & Khoiriyah, 2024)	Personalized Learning	Generative AI, such as chatbots, can personalize science learning, allowing students to tailor their learning methods to their own styles.
13.	[43] (Tan & Cheah, 2021)	Personalized Learning	The use of AI assists students in science subjects, such as physics, through personalized learning and real-time feedback.
14.	[44] (Ghariz et al., 2024)	Use in Assessment and Testing	AI technology can enhance productivity and reduce the time required to produce teaching materials.
15.	[45] (Maestrales et al., 2021)	Use in Assessment and Testing	AI technology can be used to automate the assessment process, increasing efficiency and accuracy in measuring students' understanding of complex science concepts.

Table 1 shows the impact of AI implementation on science learning. There are five main aspects of AI implementation in learning, including motivation and student engagement, understanding complex and abstract concepts, enhancing the quality of science education, personalized learning, use in assessment and testing. In each stage of learning, AI plays a role in independently providing practical and communicative learning support to students. Each form of implementation has a significant effect in supporting learning.

Regarding student motivation in science education, AI technology can significantly enhance student motivation and engagement in the classroom. Traditional learning methods have led to moderate levels of effort and interest among students in science education, with many students not fully engaging with the subject [46]. Problem-solving and critical thinking abilities are crucial parts of science education. Students are unlikely to acquire these skills if they are not interested in science [47]. Using AI technology is one technique to get children interested in science education. Wu and Yang [31] recent research highlights the ways in which AI applications in education, like tailored learning tools and intelligent tutoring systems, might enhance students' willingness to learn science. AI contributes to the creation of a compelling learning environment by providing interactive simulations, adaptive learning experiences, and personalized feedback. Giving students greater control over their education can greatly boost their intrinsic motivation to study

more about science topics. In a similar vein, Iyamuremye and Ndihokubwayo [32] draw attention to the ways in which generative AI like ChatGPT can improve student interaction and participation in the classroom. AI technologies' dynamic nature enables real-time individualized responses, which improves comprehension and adds to the fun of learning.

Since many abstract and complex topics, including the processes of iron rusting and photosynthesis, cannot be adequately taught using textbooks alone, science disciplines are frequently considered difficult [48]. The diminishing PISA (Programme for International Student Assessment) scores in Malaysia's scientific area have also been linked to a lack of comprehension of abstract concepts in science education. The incorporation of AI technology can help alleviate the problem of abstract and complex concepts. AI technologies, such as AI chatbots, can provide immediate feedback and personalized support in solving scientific tasks or problems without language barriers, allowing students to clearly understand complex and difficult science concepts [33, 34, 36]. Generative AI, like ChatGPT, can also produce clear, error-free scientific reports, which helps students better understand the structure of scientific experiment reports in a more complex and detailed manner [37].

AI technology can also improve the quality of science education. AI offers students unique ways to learn science by combining human expertise and AI in the learning process [38]. Students show deep interest in applying AI technology to enhance the learning experience through simulations and augmented reality [49]. AI technology can also generate teaching materials, both verbal (voiceover) and non-verbal (images), using generative AI like DALL-E 3 [40, 41]. By combining AI-generated verbal and non-verbal materials, learning can be significantly enhanced as it helps students better understand complex concepts by providing both verbal and non-verbal cues [50]. There are also systems that apply AI technology aimed at helping teachers conduct affective assessments by providing real-time data on students' emotions during learning activities [51]. The use of AI technology in researching emotions and behaviour in science education can provide deeper insights into the learning process, allowing teachers to plan more effective learning strategies [39]. AI technology can also help teachers create science-related learning materials, thus reducing the workload on teachers [44]. As a result, teachers have more time to plan high-quality learning experiences.

AI technology also supports personalized learning, allowing students to access education anytime, whether during or outside school hours [52]. Personalized learning with AI technology can enhance student achievement because AI can provide real-time feedback and customized content, helping them understand and retain concepts more effectively [53]. Generative AI, such as AI chatbots, can also personalize learning and provide real-time feedback in science subjects, allowing students to tailor their learning methods to their own preferences [42, 43]. Personalized learning can also be implemented through AI-generated quizzes for assessment purposes. One AI technology that can generate quizzes is Quizziz AI. The use of Quizziz AI can help teachers reduce their workload by automatically generating quizzes [54]. Through AI technology, teachers can conduct assessments automatically, enhancing efficiency and accuracy in measuring students' understanding of difficult and complex science concepts [45].

WHAT ARE THE CHALLENGES FACED IN IMPLEMENTING AI TECHNOLOGY IN SCIENCE EDUCATION?

In the field of education, particularly in science education, AI technology focuses on improving learning systems and methods as well as enhancing learning outcomes. Additionally, it aims to build the skills students need to meet the demands of their future careers [55]. However, AI technology also presents its own challenges, which educators must be cautious of and reflect upon when implementing AI technology in science education [56]. The impact of AI implementation in learning has challenges that affect teaching and learning process. These challenges are presented in Table 2.

Table 2. Findings on the Challenges of using AI Technology in Science Education

No.	Source	Impact	Finding
1.	[57] (Bagir, Onal-Karakoyun, & Asilturk, 2022)	Lack of Teacher-Student Interaction	The use of AI technology risks reducing interaction between teachers and students.

2.	[58] (Vorotnykova, 2023)	High Dependence on AI Technology	Students may become overly reliant on the use of AI technology to solve scientific problems, which can hinder the development of critical thinking and problem-solving skills.
3.	[59] (Romanov, Filatov, & Zudilina, 2022)	High Dependence on AI Technology	AI technology poses a risk of replacing human roles as educators in science education, as students may become overly dependent on the use of AI technology.
4.	[60] (Ju, 2023)	High Dependence on AI Technology	Students' dependence on AI technology in science education, without referring to traditional learning materials, can prevent them from developing critical thinking skills.
5.	[61] Park et al. 2023	Lack of Teacher Training	Many science teachers are not trained to use AI technology, leading to a gap in their ability to effectively integrate AI into their teaching.
6.	[62] OECD, 2023	Lack of Teacher Training	To include AI technology in the classroom, educators must receive enough training. The advantages of utilizing AI in science teaching cannot be completely realized without sufficient training.
7.	[63] (Gunawan et al. 2021)	Adaptation and Integration of AI Technology in the Curriculum	AI technology needs to be tailored to the curriculum and the specific learning needs of science education.
8.	[64] (AlKanaan, 2022)	Adaptation and Integration of AI Technology in the Curriculum	It can be difficult to include AI into a science program. Instructors must figure out how to make sure that the use of AI technology is in line with learning goals and standards.
9.	[37] (Erduran & Levrini, 2024)	Adaptation and Integration of AI Technology in the Curriculum	There is a need to identify relevant content from scientific practices provided by AI technology that can be effectively integrated into the school science curriculum.
10.	[65] (Baum et al., 2021)	Adaptation and Integration of AI Technology in the Curriculum	Integrating AI technology into the existing curriculum can be challenging. Educators may struggle to align AI applications with the science curriculum, such as in subjects like chemistry.
11.	[66] (Akyüz & Erdemir, 2022)	Accessibility and Quality Variation	Technical issues such as internet connectivity or software malfunctions can disrupt the performance of AI technology.

12.	[67] (Cooper, 2023)	Accessibility and Quality Variation	Although AI technology can assist in generating content and supporting educational tasks, the quality of its output can vary.
13.	[68] (Lee & Perret, 2023)	Accessibility and Quality Variation	There are barriers to accessing AI technology for science subjects, as many AI tools and services are often available primarily to students from more affluent backgrounds.
14.	[69] (Mahmudah, 2023)	Ethical Challenges	The use of AI technology in data analysis and collection can pose a threat to individual privacy.
15.	[70] (Taruklimbong & Sihotang, 2023)	Ethical Challenges	The use of AI technology in science education raises ethical questions, including how students collect and use data. There are concerns about data privacy and the potential misuse of personal information.

Table 2 displays the challenges of implementing AI in science learning. There are six main aspects identified, namely lack of teacher-student interaction, high dependence on ai technology, lack of teacher training, adaptation and integration of AI technology in the curriculum, accessibility and quality variation, ethical challenges. Each of these challenges significantly affects the implementation of AI in learning. The influence needs to be considered to support the learning process effectively.

One challenge in using AI technology in science education is the reduction of teacher-student interaction. The use of AI technology risks reducing interaction between teachers and students, which can negatively impact the learning experience and student engagement in science subjects [57]. Interaction is a crucial aspect of education, as it involves the process by which one individual influence another [71]. In other words, teacher-student interaction plays an important role in the social and emotional development of students. If teachers do not have good interaction with students where students interact more with AI technology than with teachers it can hinder the cultivation of cooperation, motivation, and overall well-being among students [72].

Excessive reliance on AI technology is another aspect that needs to be carefully considered when implementing AI in science education. AI technology has the potential to replace human roles in education, leading to students becoming overly dependent on AI for solving scientific problems [58,59,60]. High dependence on AI technology in education, particularly in science education, may prevent students from developing critical thinking skills that are essential for their future [73]. Students may also fail to achieve deep and critical learning objectives if they rely too heavily on AI technology rather than other learning materials [74]. Therefore, control over the use of AI technology in education must be exercised to ensure that students do not become overly reliant on AI, which could hinder the development of independent problem-solving skills [75].

Science teachers in schools are also often undertrained to fully adapt to AI technology, which hinders their ability to effectively integrate AI into their science teaching [61, 62]. Without adequate training, teachers face difficulties in aligning AI technology with existing science curricula, as they must ensure that the application of AI technology aligns with learning standards and objectives and is relevant to the established syllabus [37,63.64,65].

The performance of AI technology is also dependent on internet, connectivity and computer software. If students experience weak internet connections or software malfunctions, the performance of AI will be disrupted, preventing students from fully benefiting from AI technology in science education [66]. There is also a significant gap in access to AI technology among students, particularly between those from

different socio-economic backgrounds. Students from more affluent schools or families have greater opportunities to use and benefit from AI technology in science education compared to those from less privileged backgrounds, as most AI technologies come at a relatively high cost [68]. If only a select few students have access to this technology, it will create a larger gap between those who can afford it and those who cannot, leading to inequalities in academic achievement. Students with limited access to AI technology will fall behind in utilizing more advanced learning tools [59]. Additionally, AI technology provides varying levels of support in science education, and the quality of outcomes generated by AI can differ depending on how technology is used [67].

From an ethical perspective, there are several issues that need to be considered in the use of AI technology in science subjects, including privacy and data protection concerns. The use of AI in education involves the collection of large-scale personal data from students, raising serious concerns about student privacy. Without explicit authorization, the use of this data may breach students' right to privacy and create concerns about who is in charge of maintaining the data's security [69]. Additionally, there is a chance that data gathered by AI technology will be misused because student personal information could be exploited if improperly managed [70]. For instance, it would be gravely unethical for third parties to use student data gathered by AI without the students' knowledge or agreement.

CONCLUSION

Positive changes to the educational system have resulted from the integration of technology, especially in science courses. One of the many opportunities brought about by the move to digital education is the application of AI technology to improve the calibre of instruction. Prior research has demonstrated the substantial potential of AI technology to enhance student performance, particularly in disciplines like physics that call for a comprehension of intricate ideas. Chatbot from ChatGPT are a hot trend in the application of AI technology in scientific education. Applying AI to science education can improve science education quality, increase student enthusiasm and engagement, help students understand abstract and difficult topics, personalize learning, and employ AI in evaluation and testing. Lack of teacher-student connection, a heavy reliance on AI technology, a lack of teacher preparation, adapting and integrating AI technology into the curriculum, differences in accessibility and quality, and ethical issues are some of the difficulties associated with using AI in science education. This guarantees that the utilization of this technology is in line with the comprehensive growth of pupils, which includes both academic success and the procurement of necessary digital competencies for the future. Malaysia has the capacity to generate a generation that is not just highly skilled in science but also equipped to handle the demands of the digital age if the appropriate policies are put in place.

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