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A systematic review of artificial intelligence in high school STEM education research

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Abstract

The use of artificial intelligence (AI) in STEM education is becoming increasingly important, as AI has the potential to change teaching and learning methods. However, no review studies focus on summarizing research on the use of AI in STEM education in high schools. For this reason, this study aims to systematically review research on the use of AI in STEM education in high schools. We considered research articles published in journals indexed in the Scopus database. The results show that participants ranged from 1 to 50 and researchers generally used a single-group experimental teaching method. In addition, our results showed that the researchers used a variety of AI technologies in the high school context. In addition, the results showed that many variables were used to promote students in STEM education through AI-based activities. Finally, almost all studies reported positive and significant effects on students' cognitive or affective development. Overall, our findings from the review emphasize the importance of harnessing the potential of AI. More research is needed to assess learner outcomes and to conduct longitudinal studies with control or comparison groups to evaluate the long-term effects of AI interventions and establish causal relationships.

Keywords: artificial intelligence, STEM education, systematic review, high school

INTRODUCTION

Artificial intelligence (AI) in STEM education has become indispensable for today's education system. AI technologies can change STEM education teaching methods and learning processes (Chiu & Li, 2023; Xu & Ouyang, 2022). This change is supported by research on the role of these technologies in education (Li et al., 2024). Moreover, AI offers various opportunities for learners and teachers to make teaching processes in STEM education more effective (Lee & Kwon, 2024). For example, AI-based applications can create personalized learning experiences by providing tailored content based on students' learning needs. Teachers can also use AI technologies to analyze student performance and develop teaching strategies based on this data (Kim & Kim, 2022). Furthermore, the most significant advantage of AI is its ability to improve educational methods and learning experiences. For example, intelligent tutoring systems can analyze student performance and adapt learning content, accordingly, improving engagement and learning outcomes (McLaren et al., 2011; Shankar et al., 2024). In addition, AI can facilitate the integration of complex topics such as strength and movement into K-12 curricula and make them more accessible to students (Jeon et al., 2024). In this context, AI in STEM education can improve teaching quality and enhance students' scientific thinking skills (Liu & Zhong, 2024). From this perspective, AI goes beyond traditional approaches to assessing student performance and offers more dynamic and interactive teaching methods. Moreover, it also provides more effective feedback tailored to students'

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Contribution to the literature

- The use of artificial intelligence in the classroom can revolutionize the teaching and learning perspectives for students and teachers by improving various aspects such as personalized learning, achievement, learner motivation, classroom engagement and content summarization.
- However, there are no studies that specifically address the use of AI in STEM education in a higher education context. The lack of studies on STEM education in high schools therefore reveals a research gap that needs to be explored.
- The results show that almost all studies report positive and significant effects on students' cognitive or affective development. This result underlines the importance of harnessing the potential of AI.

needs (Al Nabhani et al., 2025; Asare et al., 2024; Guler et al., 2024; Santos & Corbí, 2019).

Due to these reasons, the use of AI in STEM education encourages the introduction of innovative approaches to teaching (Kim & Kim, 2022). When educators take advantage of the opportunities offered by AI and integrate these technologies into educational processes, students' interest in science can be increased, and their scientific literacy can be improved. In this context, the role of AI in STEM education covers various aspects, such as enhancing students' motivation to learn (Al Nabhani et al., 2025). For example, AI provides students with a more practical education by personalizing their learning experiences (Khurma et al., 2024). Such individualized learning can increase students' interest and strengthen their learning motivation (Lee & Kwon, 2024). In particular, instruction materials based on AI applications allow students to understand concepts better and have hands-on learning experiences (Çakıroğlu & Selçuk, 2024). In addition, all features of AI make it easier for teachers to follow innovations in science education and update their practices. Furthermore, courses that combine AI with hands-on activities can stimulate students' interest in STEM subjects and enhance their thinking and problem-solving skills (Hwang et al., 2022; Çakıroğlu & Selçuk, 2024).

In terms of these perspectives, AI technology has emerged as a new research trend in education and has become a part of teaching systems in STEM education. Although AI is important for STEM education, very few studies have systematically reviewed research studies focused on the effects of AI on STEM subjects. For example, Lee and Kwon (2024) investigated the status of AI education in K-12 schools and examined topics, teaching approaches, and learning outcomes. They examined 25 articles published between 2018 and 2023. Their findings show the benefits of AI education in improving AI literacy and problem-solving skills, as well as ethical considerations, fostering motivation, positive attitudes concerning AI, and interest in technology, and raising career aspirations for AI.

Xu and Ouyang (2022) systematically examined 63 empirical research from 2011 to 2021. Their findings explored the impact of AI on STEM education. They defined six categories of AI applications and found evidence for the distribution of AI categories with other elements (i.e., information, object, medium, environment) in AI-STEM. In addition, the study revealed the pedagogical and technological implications of AI in STEM education. Li et al. (2024) analyzed 47 empirical studies to summarize the research findings on the outcomes of AI educational programs in K-12 education. The results revealed positive results regarding the effectiveness of well-designed hands-on tasks to promote deep understanding and engagement.

Similarly, Liu and Zhong (2024) examined 45 empirical studies on AI instruction for K-12 students. Their findings show that K-12 AI education can potentially develop students' AI literacy, including AI knowledge, AI affectivity, and AI thinking. However, they pointed out shortcomings in research and instructional design, including short durations, small sample sizes, non-standardized research methods, lack of long-term and cross-age AI curricula, etc.

In another research, Yusuf et al. (2024) reviewed and mapped 407 publications indexed in various databases. They defined eight themes. They found that GenAI was conceptualized as a tool for 'pedagogical improvement', 'specialized training and practices', 'writing assistance and productivity', 'professional skills and development', and as an 'interdisciplinary learning tool'. They emphasize that there is little research and discussion of GenAI in K-12 education, limited research on the impact of GenAI with experimental procedures, and limited exploration of the potential and ethical concerns from a cultural dimensions perspective.

All these reviews suggest that using AI in instruction can revolutionize teaching and learning perspectives for students and teachers by improving various aspects such as personalized learning, achievement, learner motivation, classroom engagement, and content summarization. However, it is clear from these studies that no studies specifically address the use of AI in STEM education in a higher education context. Therefore, the lack of studies on STEM education in high schools reveals a research gap that needs to be explored in existing literature. Furthermore, the effective integration of AI into STEM education can be understood by synthesizing the research findings. Therefore, this article

Table 1. A list of used keywords for searching for studies

Keywords	Keywords used	Search area
Artificial intelligence	Artificial intelligence, machine learning, neural networks, deep learning algorithmic intelligence, machine intelligence, intelligent systems, computational intelligence, & AI	Keywords
Science education	Science education, biology education, chemistry education, physics education, & STEM education	Keywords
High school	High school & secondary school	Title-abstract-keywords

aims to systematically review the research on the use of AI in STEM education in high schools.

METHOD

In this research, we used a systematic review approach. A systematic review critically evaluates and synthesizes all studies on a given topic by combining and applying strategies based on its aims (Newman & Gough, 2019). Systematic methods are the most reliable way to synthesize and understand the results of studies with a specific research focus. Systematic reviews are often seen as the pinnacle because their results involve a more detailed literature search (Newman & Gough, 2019). With systematic review in this research, we examined studies on the use of AI in STEM education in the high school context and critically evaluated based on the aims and results of this research.

Data Collection

To collect data in this systematic review, the authors searched relevant studies in the Scopus database to collect data for this study. The inclusion criteria of the studies included in the research are as follows:

- Studies in STEM education
- Studies conducted with high school students
- Only peer-reviewed articles
- Only empirical studies
- No period for published articles

These criteria were set for this study, and the number of studies included in the research was determined based on the inclusion and exclusion criteria. We searched the keywords determined for the main keywords: "artificial intelligence," "science education," and "high school."

Table 1 shows a list of alternative keywords used for the main keywords. After all these processes, the appropriate studies to be included in the research were finalized. In the initial search, we found 188 documents. Later, we used filtering options, including journal as source type and English as publication language. Thus, the number of documents decreased to 47. Later, we chose articles and review options as document types. The number decreased to 45. After this, two researchers read the titles and abstracts simultaneously. After this, we excluded 37 articles for analysis and decided to include eight articles in the analysis. For analysis, we reached the full text of each article. While conducting this data collection process, we followed a PRISMA flowchart, showing how these studies were reduced to eight (Moher et al., 2009). PRISMA is the review protocol adopted for this study. All studies that fell outside the inclusion criteria were excluded in this study.

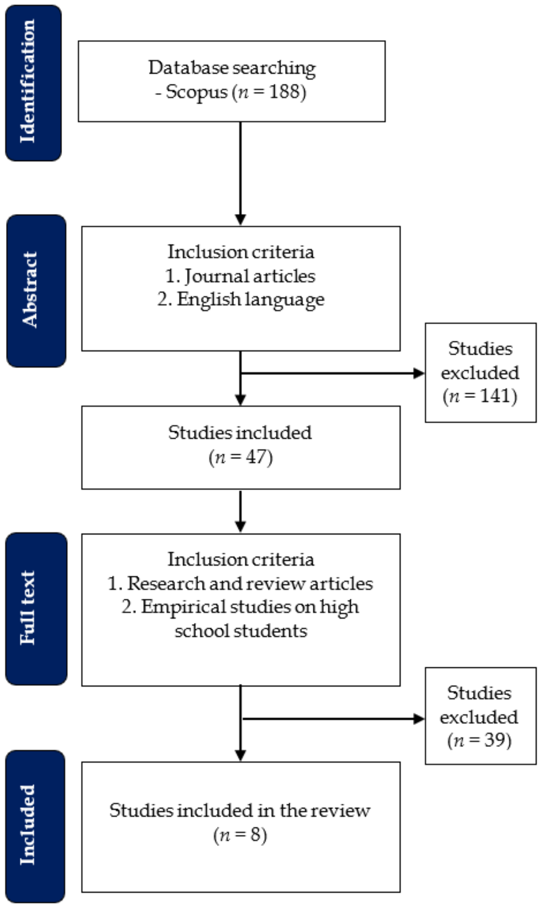

Figure 1. PRISMA flowchart for articles that fulfilled the inclusion criteria (Source: Authors' own elaboration)

Figure 1 shows the PRISMA flowchart for collecting studies reviewed in the present study.

In addition, **Table 2** shows a list of articles used in the review.

Additionally, all details about the reviewed studies are given in **Appendix A**.

Data Analysis

The researcher developed a data coding form to analyze the study data by considering the features of the reviewed studies. The data coding form included

Table 2. A list of articles used in the systematic review

Authors	Title	PY	Source title	Country
Bosch (2021)	Identifying supportive student factors for mindset interventions: A two-model machine learning approach	2021	Computers and Education	The USA
Çakiroğlu and Selçuk (2024)	Machine learning meets secondary school classrooms: Using hands-on activities to advance computational thinking	2024	Education and Information Technologies	Turkey
Jeon et al. (2024)	A staged framework for computer vision education: Integrating AI, data science, and computational thinking	2024	Applied Sciences	South Korea
Katz et al. (2021)	Linking dialogue with student modelling to create an adaptive tutoring system for conceptual physics	2021	International Journal of Artificial Intelligence in Education	The USA
Oskotsky et al. (2022)	Nurturing diversity and inclusion in AI in Biomedicine through a virtual summer program for high school students	2022	PLoS Computational Biology	The USA
Santos and Corbí (2019)	Can Aikido help with the comprehension of physics? A first step towards the design of intelligent psychomotor systems for STEAM kinesthetic learning scenarios	2019	IEEE Access	Spain
Sikström et al. (2024)	Pedagogical agents communicating and scaffolding students' learning: High school teachers' and students' perspectives	2024	Computers and Education	Finland
VanLehn et al. (2016)	Learning science by constructing models: Can Dragoon increase learning without increasing the time required ?	2016	International Journal of Artificial Intelligence in Education	The USA

Note. PY: Publication year & Country: The country of corresponding author

information on all variables (year, author, place of study, etc.) and research characteristics (variables such as method, participants, type of AI used, etc.) that can critically evaluate individual studies. The study's title, author, year of publication, and number of participants were coded for each study. Two researchers evaluated the articles during the data analysis process. In this study, "inter-coder reliability" was calculated. The study used "agreement rate" as a measure of reliability. The agreement was found to be 92% for all studies. A third researcher was consulted when discrepancies occurred.

RESULTS

Study Characteristics

Our systematic review of AI in high school STEM education includes studies from six countries–the United States (the USA), Spain, Turkey, South Korea, Finland, and Estonia–and yielded 41 authors from these countries. This geographic diversity underscores the universal appeal of AI technologies in different parts of the world. Of the eight articles, five papers were from the USA and one from Spain. The remaining authors published an article on AI in STEM education in schools, including Turkey, South Korea, Finland, and Estonia.

Characteristics of Participants

The demographic data of the participants in the study show a wide range in terms of the number of participants. The number of participants in these studies varies considerably. Sikström et al. (2024) studied 16 students who were enrolled in high school. The study by Çakıroğlu and Selçuk (2024) involved 20 high school students in hands-on activities to improve their computational thinking (CT) skills through machine learning applications. The study by Oskotsky et al. (2022) involved 29 high school students in their research to improve diversity and inclusion in AI in biomedicine and provide them with AI education and hands-on research experiences. Santos and Corbí (2019) studied 30 high school students, while Jeon et al. (2024) studied 40 high school students. The other two studies by Katz et al. (2021) and VanLehn et al. (2016) involved 145 students in their research. Bosch (2021) investigated the role of mindset interventions in the academic environment with 10870 students, mainly through the lens of machine learning approaches. The study included a large group of participants. This large-scale study examined the effects of a growth mindset intervention on academic performance, specifically on improving the GPA of underachieving high school students. The studies in the review provide information on the number of participants involved in using AI in STEM education in high schools. In addition, the number of participants in almost all studies indicates a strong trend towards developing and using personalized AI in STEM education that responds to and considers students' needs. These studies contribute to the findings reported in the studies and support the notion that AI-driven STEM education is more beneficial when carefully tailored to characteristics of the targeted demographic.

Study Design

Of the eight articles, seven articles used an experimental teaching method. Among these seven studies, many of them used an experimental teaching method with a group that included a pre-test and post-test method in one group (Bosch, 2021; Çakıroğlu & Selçuk, 2024; Jeon et al., 2024; Oskotsky et al., 2022; Santos & Corbí, 2019). The other two studies (Katz et al., 2021; VanLehn et al., 2016) used an experimental teaching method and included control and experimental groups to test differences before and after teaching. Only Sikström et al. (2024) used interviews and focus groups to investigate the role of pedagogical agents in improving student learning by assessing high school students' perceptions. These findings indicate that many studies generally favored a single-group experimental teaching method to examine the impact of their instruction on the development of high school participants with AI and STEM education. However, a smaller number of studies used control and experimental groups simultaneously. This finding shows a notable deficit in the use of control groups. The low prevalence of control groups underscores the need for more rigor in identifying causal relationships between AI interventions and STEM education. Describing the impact and contribution of AI-enhanced STEM education on students' learning and affective outcomes is essential.

Artificial Intelligence Technologies Used

Integrating AI into STEM education represents an important shift in how this new technology is used in the classroom. Our findings show that researchers use various AI technologies in high school STEM education. These ranged from intelligent tutoring systems (Santos & Corbí, 2019; VanLehn et al., 2016), Python (Oskotsky et al., 2022), machine learning (Bosch, 2021; Çakiroğlu & Selçuk, 2024; Oskotsky et al., 2022), the use of neural network-based AI and symbolic AI (Jeon et al., 2024), human-machine communication (Sikström et al., 2024) and tutorial dialogue systems (Katz et al., 2021). This diversity of AI technologies in STEM education underlines the ability of AI to address a wide range of its implementation in the classroom.

Targeted Variables

Using variables to develop AI in STEM education is essential to inform researchers about the impact of studies on learning outcomes. Our results showed that researchers have used many variables to promote them in high school STEM education through AI-enhanced activities. For example, the study by Oskotsky et al. (2022) examined whether students knew people in the field of AI, whether they were confident to talk about AI, and whether they knew what careers were available in the field of AI. In addition, Sikström et al. (2024) investigated the effects of pedagogical agents on students' learning and instructional communication skills. The research of Çakıroğlu and Selçuk (2024) dealt with CT skills. While Santos and Corbí (2019) investigated the understanding of some physics concepts, Jeon et al. (2024) examined interest, subject knowledge, and the use of AI. In addition, Katz et al. (2021) investigated the development of students' satisfaction and problem-solving skills. VanLehn et al. (2016) also included variables from an open response test and a concept mapping task. Finally, Bosch (2021) used students' GPA scores as a variable. These results suggest that although all studies target the use of AI in the same participant groups, there is a notable lack of results from different studies on the same outcome variables.

Key Findings

The key findings of each study provide valuable insights into the innovative approaches and methods developed to improve educational outcomes and expand the use of AI in various subjects, particularly in STEM education. For example, Oskotsky et al. (2022) examined the impact of a virtual summer program designed to promote diversity and inclusion in AI, particularly in biomedicine. The article describes how the program targeted high school students from underrepresented backgrounds to provide them with AI education and hands-on research experiences in biomedicine. The results show that participants are significantly more familiar with data processing and machine learning algorithms and more confident discussing AI. Significantly more students were familiar with working with data and evaluating and applying machine learning algorithms. There were also nominally significant increases in students' connections to people from historically underrepresented groups in AI, their confidence in discussing AI, and their awareness of careers in AI. Improving participant diversity and inclusivity. The researchers emphasize the program's effectiveness in increasing students' familiarity with working with data and machine learning and expanding their awareness of AI careers, ultimately laying the groundwork for future AI education initiatives.

In another study, Bosch (2021) analyzed how computer-based interventions can be tailored based on identified student attributes to maximize positive educational outcomes, particularly in promoting a growth mindset, which has been shown to have varying degrees of success with different student populations. They examined the role of mindset interventions in academic settings, mainly through machine learning. Students who participated in the experiment group were involved in two 25-minute sessions. They found that the intervention was most effective for students with low academic achievement and that blocked navigations predicted an intervention effect of only 0.185 GPA points below the mean. They also found that some minority students would benefit less (or less) from the intervention. The study identified factors that promote student engagement and achievement. While a growth mindset intervention improved grade point averages among lower-performing 9th-grade students, the outcome varied among different demographic groups, raising questions about the universal applicability of such interventions and highlighting the importance of tailoring educational strategies.

Jeon et al. (2024) aim to develop a stage-by-stage framework for computer vision education by integrating neural network-based AI and symbolic AI in each stage. They conducted a study to test the effectiveness of AI-integrated instruction in four lessons. The lessons improved students' understanding and engagement with these topics. Specifically, their results showed statistically significant improvements in students' interest in using AI in a science topic, scientific understanding, a significant improvement in students' practical application of AI, and students' understanding of integrating AI and computer vision in scientific exploration. This structured approach provides educators with a roadmap for implementing practical, hands-on learning experiences and contributes significantly to advancing AI education in schools.

Santos and Corbí (2019) investigated the potential of psychomotor intelligent tutoring systems that use wearable technology to capture human motion, enhance the learning experience, and provide personalized feedback for understanding physics concepts in high school students. They found that the proposed approach benefits the learning of STEM concepts and techniques from Aikido, using intelligent tutoring systems can facilitate the understanding of physics concepts in high school students, suggesting a broader application of martial arts in STEAM education. Their empirical study with high school students concluded that watching Aikido demonstrations can effectively teach complex physics concepts, such as movement, by engaging students cognitively and physically. This innovative pedagogical approach aligns with the growing interest in integrating arts and STEM education to improve learning outcomes.

Sikström et al. (2024) explored the pedagogical role of agents in education and investigated how these agents can facilitate learning through communication and scaffolding techniques. They analyzed how these agents can effectively communicate and provide scaffolding techniques to achieve better educational outcomes. Their results showed that students had positive feelings and adapted to the students' emotional state concerning PA communication. Students indicated that PAs could improve students' self-perceptions by supporting self-efficacy and self-regulated learning. Thus, the results emphasize the benefits of pedagogical agents from the students' perspective and show that interaction with such agents can enhance the learning experience and outcomes.

Katz et al. (2021) focused on adaptive tutoring systems for conceptual physics and showed how a dialog can be integrated with student modeling to provide tailored learning experiences. To this end, they investigated the integration of dialog systems with student modeling techniques to develop an adaptive tutoring system (Rimac) explicitly designed for teaching conceptual physics. They found that students with low and high prior knowledge showed significant learning gains between pretest and posttest. However, students with extensive prior knowledge who used the experimental version learned more quickly than those who used the control version. Students with extensive prior knowledge who employed the student model as a tutor required less time to complete the intervention. Nonetheless, they learned the same amount as students who utilized the control version. A further study discovered that students with high and low prior knowledge learned more effectively with a tutor version that dynamically modified its student model during dialogs than with the control version. The research focuses on improving personalized learning experiences by tailoring interactions based on student's understanding and needs to improve physics learning outcomes. The results show that adaptive systems can effectively address individual learning needs to promote retention and understanding of physics concepts.

Finally, VanLehn et al. (2016) investigated the potential of "Dragoon" as an intelligent tutoring system to improve science learning by constructing models without increasing overall instructional time. They examined the effectiveness of the Dragoon tool in enhancing learning experiences in high school education. They concluded that model construction could be a viable method for teaching science, and the experiments showed that this goal was achieved. In all three studies, the amount of time spent teaching Dragoon was similar to that spent teaching the control. In addition, study 2 and study 3 suggest that Dragoon may have provided better knowledge of the target system as expected from model building compared to instruction without model building. The article emphasizes model construction as a pedagogical strategy guided by epistemological theories of knowledge acquisition and understanding. The study attempts to provide meaningful insights into pedagogical practices in AI and science learning environments by analyzing the relationship between tool use, learning efficiency, and time management. Their findings suggest that systematic engagement with the construction of models can lead to significant improvements in learning, confirming the effectiveness of innovative teaching tools in promoting inquiry-based science education. In summary, this study highlights the transformative potential of creative teaching methods, integrative programs, and interdisciplinary approaches to enhance learning experiences in various subjects.

Çakiroğlu and Selçuk (2024) investigated hands-on activities in secondary school classrooms to improve students' understanding of machine learning concepts and to examine the effects of machine learning activities on secondary school students' CT skills. They discussed the integration of machine learning into the secondary school curriculum through hands-on activities. The primary purpose is to enhance students' CT skills and improve their understanding of computer science concepts in a pedagogical setting. The results showed that the activities contributed positively to developing the dimensions of abstraction, decomposition, algorithm design, and pattern recognition of CT. The results also showed that the students who participated in the machine learning activities performed differently on the dimensions of CT. Their study suggests that hands-on engagement leads to improved CT skills, emphasizing the importance of active learning strategies in fostering a deeper understanding of complex topics in technology and computer science.

Based on the results of these studies, it is clear that all studies have examined the use of technological innovations (AI, computerized interventions, adaptive teaching systems, etc.) in education. Secondly, almost all studies applied different educational interventions to students over a period of time and analyzed their results. Third, most studies assessed students' cognitive or affective development. In particular, AI, machine learning, and computerized education systems are emphasized to increase students' interest and improve their academic performance. Fourth, all studies analyzed variables that differed according to students' objectives and needs. Fifth, some studies (e.g., Jeon et al., 2024; Oskotsky et al., 2022) aimed to increase education and awareness of AI. Some studies (e.g., Santos & Corbí, 2019) have investigated their impact and developed innovative approaches to teaching physics (e.g., Aikido). Other studies (e.g., Katz et al., 2021; VanLehn et al., 2016) have examined the effects of adaptive teaching systems or modeling tools on learning. Finally, some studies (e.g., Oskotsky et al., 2022; Sikström et al., 2024) used questionnaires, observations, and students' perceptions to assess their objectives, while others (e.g., Katz et al., 2021; VanLehn et al., 2016) used tests to answer their research questions.

DISCUSSION

This systematic review presents a comprehensive overview of the use of AI in STEM education to support teaching and student learning outcomes. The findings highlight the use of AI-powered interventions and the positive impact on student learning outcomes, emphasizing the potential of AI to deliver personalized and contextualized STEM education that increases user engagement. First, our results showed that the studies in this systematic review were from six countries, including the USA, Spain, Turkey, South Korea, Finland, and Estonia, and 41 authors from these countries. This finding demonstrates geographic diversity and highlights the universal appeal of AI technologies for STEM education in different parts of the world.

Second, the demographic data of the study participants show a wide range in terms of the number of participants. However, our results show that, in general, the number of participants ranged from 1 to 50. This result may be explained by the researchers attempting to recruit participants from a conventional sample. Overall, the number of participants in almost all studies indicates a strong trend toward developing and using personalized AI in STEM education that is responsive to students' needs. Thirdly, in terms of study design, the results show that researchers generally used a single-group experimental teaching method to investigate the effects of their AI teaching. However, control and experimental groups were used simultaneously in fewer studies. This finding highlights a notable gap in the use of control groups. Control groups' low prevalence underscores the need to investigate causal relationships between AI interventions and STEM education. This gap is critical for future research to characterize the impact and contribution of AI-supported STEM education on student learning and affective outcomes. This result confirms the findings of Liu and Zhong (2024). Similarly, they pointed out their concerns regarding shortcomings in research and instructional design, including short durations, small sample sizes, non-standardized research methods, lack of long-term and cross-age AI curricula, etc.

Fourth, our results showed that researchers have used a variety of AI technologies in high school context. These included rom intelligent tutoring systems (Santos & Corbí, 2019; VanLehn et al., 2016), Python (Oskotsky et al., 2022), machine learning (Bosch, 2021; Çakiroğlu & Selçuk, 2024; Oskotsky et al. (2022), the use of neural network-based AI and symbolic AI (Jeon et al., 2024), human-machine communication (Sikström et al., 2024), and tutorial dialog systems (Katz et al., 2021). This diversity of AI technologies in STEM education underscores the ability of AI to address a wide range of implementations in the classroom. Therefore, there is a greater need for researchers to obtain helpful information and results regarding implementing other AI-powered applications for the use of subjects in STEM education.

Fifth, regarding the variables used in the studies examined, the results revealed that many variables were used to promote students in STEM education through

AI-based activities. These variables included many variables, including from the study that examined whether students knew people in the field of AI, whether they were confident to talk about AI, and whether they knew what careers (Oskotsky et al., 2022), pedagogical agents (Sikström et al., 2024), CT skills (Çakıroğlu & Selçuk, 2024), understanding of some physics concepts, interest, subject knowledge, and the use of AI (Jeon et al., 2024). In addition, it investigated the development of students' satisfaction and problem-solving skills (Katz et al., 2021), an open response test and a concept mapping task (VanLehn et al., 2016), and changes in GPA scores (Bosch, 2021). This result is very similar to those of Lee and Kwon (2024), whose findings showed that K-12 AI lessons cover various topics, including basic AI concepts, different types of AI, AI applications, and ethical considerations related to AI. These findings suggest that although all studies aim to use AI with the same participant groups, there is a notable lack of results from different studies on the same outcome variables. This means that more research is needed on the effects of AI in STEM education in the high school context.

Sixth, regarding the main findings, we found that all studies focused on the effects of AI in the classroom and applied different educational interventions over time. Nearly all studies reported positive and significant impacts on students' cognitive or affective development. Research has shown that AI, machine learning, and computerized education systems have increased interest in academic achievement. All studies analyzed variables that differed according to students' goals and needs. This result is very similar to those of Lee and Kwon (2024), who reviewed studies on AI education in K-12 schools and found the benefits of AI education in improving AI literacy, problem-solving skills, and ethical considerations of the societal impact of AI. They also reported that AI fostered motivation and positive attitudes, raising career aspirations. Similarly, Xu and Ouyang (2022) reported the impact of AI in STEM education. In another research, Li et al. (2024) reported the effectiveness of well-designed AI hands-on tasks that promote deep understanding and engagement. Regarding the potential of AI in teaching, our findings parallel those of Liu and Zhong (2024), who indicated the potential to develop students' AI literacy, including AI knowledge, AI affectivity, and AI thinking.

Overall, our findings from the review underline the importance of harnessing the potential of AI in STEM education. In terms of this result, our results are very similar to those of Yusuf et al. (2024). However, there is a lack of studies at a broader level covering some subjects in STEM education. This gap, therefore, shows that AI-supported interventions in STEM education are still in their infancy. Even though the technological advances in AI may be overstated, it is evident that using AI in STEM education requires a lot of effort and implementation. Efforts should be made in the future to close this gap and ensure a balanced integration of technological advances and practical implementations.

This research shows the importance of integrating AI into STEM education, including using various AI interfaces and applications that involve personalizing content for specific groups of participants. In addition, using AI to improve the best implementation samples can increase the effectiveness of STEM instruction by improving engagement in the future. When these areas are considered, STEM lessons can be more effectively designed to meaningfully engage students and promote understanding and implementation in STEM lessons.

Recommendations

The systematic review highlighted important implications for integrating AI into STEM education to inform researchers working on an AI model. In light of our findings, the importance of interdisciplinary collaboration in using AI in STEM education research becomes apparent. Scientists must, therefore, focus on working closely with AI experts to teach STEM subjects through supported activities and realize AI's full potential in STEM education research. This interdisciplinary approach can lead to further development of research on this topic and produce more beneficial, practical, and impactful strategies for the use and implementation of AI in teaching and learning. In addition, AI enables teachers at all levels to tailor their course content for students based on their individual preferences and needs, resulting in more relevant and engaging content. STEM teachers should leverage AI's ability to effectively segment audiences and deliver personalized messages tailored to specific demographics and instructional needs.

Furthermore, another missing point from the reviewed articles discussed in this paper is targeting AI-powered content to different demographics and priorities. Tailoring content to specific demographics can enhance its relevance and impact, making incorporating AI a crucial area for development in future STEM education.

Overall, integrating AI into STEM lessons offers exciting opportunities to develop more effective and personalized teaching strategies and learn about the effectiveness of teaching with AI. With the rapid development of AI, teachers and educators can harness its power to achieve positive learning outcomes and improve the state of STEM education in different regions of the world.

For future research, based on our findings, we suggest using more objective measures of learner outcomes and conducting longitudinal studies with control or comparison groups to assess the long-term impact of AI interventions and establish causal relationships. In addition, it is also necessary to focus on the relationship between theory and practice in AI-enhanced STEM education to develop frameworks that integrate existing theories with new technologies. This requires interdisciplinary approaches and methods combining AI technology with teaching insights. In addition, future research should focus on specifying the characteristics or dimensions of individual AI applications. Another line of research should focus on ethical use to ensure the responsible use of AI in STEM education and to protect user privacy and trust. This will enable STEM teachers and educators to utilize the potential of AI better to improve learning outcomes.

CONCLUSION

This paper aims to review studies focusing on AI-supported interventions in STEM education systematically. The results show that AI delivers positive and significant learning outcomes for learners at the high school level. Thus, the results suggest that AI in STEM education has the potential to create and disseminate content that engages learners. This review has outlined the current state of research and highlighted the focus of AI in STEM education. Based on our findings, we conclude that integrating AI with established learning theories and maintaining a strong ethical foundation will enable the development of effective, trustworthy, and impactful AI-supported STEM interventions. In summary, this review provides valuable information about the current state of AI in STEM education, adds new insights into the literature, and provides direction for future research.

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APPENDIX A

Table A1. List of reviewed studies in the study

Authors	Aims	n	Study type	VE	AI details	Key findings
Santos and Corbí (2019)	Examined the potential of psychomotor intelligent tutoring systems that utilize wearable technology to capture human motion to enhancing the learning experience and provide personalized feedback.	30	Experimental (pre-post-test)	Some physics concepts	Intelligent tutoring systems	+A positive increase in comprehension of physics concepts
Oskotsky et al. (2022)	Aims to enhance diversity and inclusion in the field of AI within biomedicine and provide them with AI education and hands-on research experiences.	29	Experimental (pre-post-test)	Knowing, confident & aware of careers	Python & machine learning	+An increase in confidence regarding AI +A significant increase in the students' knowing people in AI and their awareness of careers in AI
Jeon et al. (2024)	Aims to develop a staged framework for computer vision education by integrating neural network-based AI and symbolic AI in each stage.	40	Experimental (pre-post-test)	Interest, subject knowledge, & use of AI	Neural network-based AI and symbolic AI	+Statistically significant improvements in students' interest in the subject +An increase in scientific understanding +A significant enhancement in students' practical application of AI
Bosch (2021)	Analyzing the role of computer-based interventions in identifying student attributes to maximize positive educational outcomes particularly across diverse student populations.	10,870	Experimental (pre-post-test)	Change in GPA	Machine learning methods	+The intervention was most effective for students with prior low academic achievement
Sikström et al. (2024)	Aims to analyze how pedagogical agents can effectively communicate and provide scaffolding thereby facilitating better educational outcomes.	16	Interviews & focus groups	Learning, instructional communication capabilities of pedagogical agents	Human–machine communication	+Positive feelings and adapts to emotional state +Positive results to enhance students' perceptions of self-efficacy and self-regulated learning
Çakiroğlu and Selçuk (2024)	Aims to investigate the impact of machine learning activities on the computational thinking skills of secondary school students.	20	Experimental (pre-post-test)	CT skills	Machine learning activities	+A positive development in CT skills
Katz et al. (2021)	Explored the integration of dialogue systems with student modeling techniques to develop an adaptive tutoring system specifically designed for teaching conceptual physics.	145	Experimental (control and experimental groups)	Satisfaction & problem-solving	Tutorial dialogue systems	+Significant learning gains +The tutor took less time to complete the intervention but learned a similar amount as students in control group +Learning more efficiently from a version of the tutor
VanLehn et al. (2016)	Explored the effectiveness of the Dragoon tool in enhancing learning experiences in high school education.	145	Experimental (control and experimental groups)	Open response test and a concept mapping task	Intelligent tutoring system	+A significant effect on the effectiveness of the Dragoon tool

Note. n: Number of participants & VE: Variables examined