Artificial Intelligence in University Science Education: A Systematic Review of Trends, Challenges, and Opportunities for Learning Outcomes

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Abstract. This systematic review illustrates to what extent artificial intelligence is important in higher-level science learning by using the frameworks of constructivist learning theory and cognitive load theory for guidance. After carefully reading through the 9 studies, it was obvious that AI tools not only facilitate personal learning but also help students develop their problem-solving skills. However, AI's effects really differ depending on the subjects: Mathematics and Computer Science seem to receive greater attention than any other field. There is also a noticeable gap about the impact of AI on learners: the existing research usually gives educators' viewpoints precedence over firsthand accounts of students' experiences. AI indeed presents more chances to enhance science education, but issues like students' increasing cognitive load still need to be addressed further. This analysis provides important insights for improving learning experiences in higher science learning and emphasizes that more research should maximize AI integration in the future.

Keywords: Artificial Intelligence, Science Education, Constructivist Learning Theory, Cognitive Load Theory, Problem-Solving Skills

1. Introduction

The purpose of this systematic review is to bring a starting point for touching on the huge gaps in AI's effects on student engagement, performance, and learning experiences. By going over the details of some research that relates to scientific learning at the university level, it can be observed that as AI is finding its way into the aspect of education from time to time, more research is still needed to determine and conclude how AI actually influences STEM fields in higher education [1]. It's common that previous studies have already demonstrated AI technologies can offer adaptive feedback and personalized learning, but their application really differs widely in effectiveness within fields [2]. This study evaluates how AI could improve learners' problem-solving skills and personalize learning and provides this as part of the conclusion through an analysis of 9 studies. Furthermore, it also addresses potential limitations such as cognitive overload and students' excessive dependence on AI technology. In order to improve learning outcomes, this article aims to

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provide insights that can guide the successful integration of AI into advanced higher-level science learning.

According to the existing studies, science subjects like Biology are receiving less attention than disciplines like Mathematics and Computer Science when it comes to the use of AI [3]. Additionally, rather than emphasizing how AI influences learners' learning experiences and outcomes, a large portion of previous work preferred the viewpoints of educators and academics over students themselves [4]. Given, as the U.S. Bureau of Labor Statistics reports, STEM fields are expanding at a rate that is noticeably faster than non-STEM fields, it is imperative to comprehend the successful integration of AI in order to adequately prepare students for careers in these industries [5]. The purpose of this review is to summarize recent research in order to respond to the following query:

What are the trends and patterns in existing research regarding the role of artificial intelligence in university science education?

2. Theoretical framework

The analysis here is mainly based on Constructivist Learning Theory (Jean Piaget, Jerome Bruner) and Cognitive Load Theory (John Sweller). Constructivist learning theory, as illustrated by Jean Piaget, believes that students will actively create their knowledge of the world by interacting with it and using their prior knowledge [6]. According to this notion, the learning procedure is more likely to be an active process in which students interact meaningfully with the material to generate knowledge via their own investigation rather than just being passive recipients of it. Conversely, the Cognitive Load Theory proposed by John Sweller highlights the necessity of instructional design that regulates cognitive load [7]. According to Sweller, students' learning would be less successful when their assignments are overly complicated or disorganized as these raise 'irrelevant cognitive load' and make it harder for students to understand [8]. He also suggested that instructional design should prioritize 'information transfer mode' above 'problem solving mode' since this will help students comprehend and assimilate information more efficiently.

In terms of this study on the role of artificial intelligence in university science education, both theories are highly relevant and form the basis of this research. Students' use of AI tools in learning STEM subjects reflects Constructivist Learning Theory, as they actively interact with AI to build and deepen their understanding of scientific concepts. Meanwhile, Cognitive Load Theory provides an eye to view how AI may decrease excessive cognitive burden, assist students in better managing complicated knowledge, and ultimately enhance learning results. Therefore, in order to improve and modernize students' scientific learning in college, this article explored whether integrating AI can benefit STEM education by combining these fundamental theories.

3. Methods

3.1. Literature search

In this study, a systematic literature review approach was adopted. A literature search was conducted by using the EBSCOhost database to ensure a comprehensive collection of relevant studies on the role of AI in university science education. The search was conducted on August 25, 2024, using a combination of keywords and subject headings, such as 'artificial intelligence,' 'university,' and 'science education,' as outlined in Table 1. These search terms were combined using the Boolean operator 'OR' to capture a broad range of relevant studies, while 'AND' was used to connect different categories, narrowing down the results to those most relevant to the research focus. The

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search encompassed all publications available up to that date, ensuring that both recent and earlier studies were reviewed. 255 studies were identified as relevant to the given keywords and imported into Covidence, a review management tool, for further screening and analysis, according to the main idea of OpenAI [9].

Table 1: A combination of both search terms and keywords used in EBSCOhost

Search Categories	Search Terms	Where did these search terms need to be: Abstract? Full text? Keywords?
Artificial intelligence	Al or "automatic technology" or automation or robotization or "machine inteligence" or "intelligent retrieval" or "information retrieval" or "artificial intelligence" or "machine learning" or "neural networks" or "cognitive computing" or "intelligent systems" or "smart technology" or "autonomous systems" or "computational intelligence"	AB(Abstract)
University	college or academy or institute or seminary or academia or "graduate school" or "higher education" or graduate or undergraduate or postgraduate or "school of advanced studies" or "graduate institution" or "academic institution"or higher-level or "higher level" or university or institution or "educational institution" or academe or "higher educational institution" or "higher education institution" or "educational establishment" or "higher education establishment"	AB(Abstract)
Science Education	"scientific instruction" or "scientific education" or "scientific training" or "scientific divulgation" or "science literacy" or "science learning or "science awareness" or "science pedagogy" or stem or "education science" or "scientific understanding" or "science idea" or "science theory" or "mathematical theory" or "science education" or "dissemination of science"	AB(Abstract)

3.2. Literature screening

By using the structure of OpenAI provided [9], it’s noticeable that Covidence automatically removed 2 duplicate records, leaving 253 studies for the initial screening process. These remaining studies were then screened by examining their titles and abstracts according to the following inclusion and exclusion criteria:

1. The study must focus on university students (excluding studies about secondary/lower-level students, teachers, or parents).
2. The study must emphasize science learning, including various subjects such as Mathematics, Physics, Chemistry, Astronomy, and other related fields.
3. Eligible studies had to be written in either English or Chinese.
4. The research must specifically mention AI or closely related topics.

As shown in PRISMA diagram (Figure 1), this initial screening excluded 202 studies that did not meet the criteria, leaving 51 articles for full-text review. Then, the retrieval of the full texts of these articles from various sources and a more detailed assessment based on the same inclusion and exclusion criteria were done. During this stage, studies that were not focused on university-level students, did not emphasize science learning, or failed to specifically address AI were excluded. This process ultimately left 9 studies that met all of the criteria for detailed analysis.

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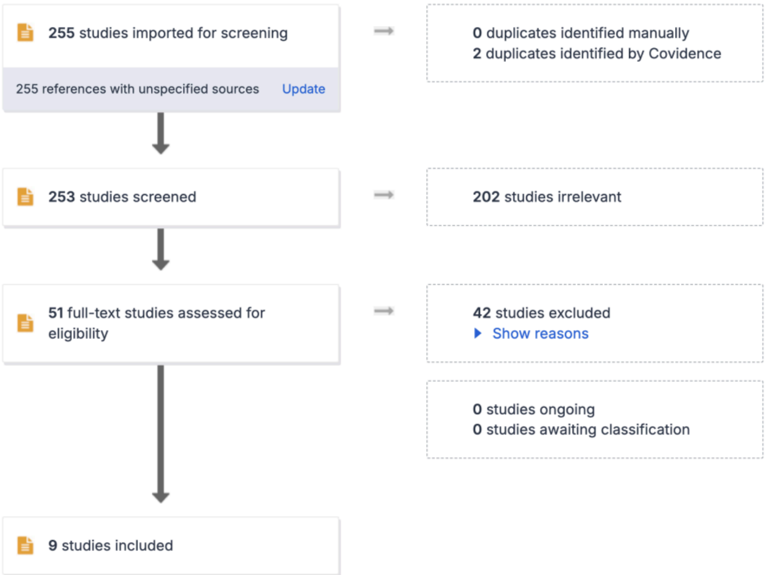

Figure 1: A PRISMA diagram from covidence

3.3. Literature analysis

After completing the screening process, thorough data extraction and coding were conducted to analyze how the selected studies discussed the application of AI in university science education. Specifically, how each study addressed the role of AI in enhancing science learning, student engagement, and the development of AI-driven assessment tools in higher education contexts was examined. The literature was then categorized into themes based on AI's impact on personalized learning, student engagement in science subjects, and the use of AI in assessment systems.

After finishing the full-text screening, the number of articles was quantified within each category, and these counts were converted into proportions to analyze the overall distribution of the literature. Based on this analysis, graphs were made to represent how the studies were categorized visually and their primary areas of focus, as shown in Table 2, which will be carefully discussed in the next part of this article. This helped to provide a clearer picture of the trends and patterns in existing research on AI's role in university science education.

Table 2: Examples for how studies were categorized and their primary areas of focus

Covidence #	Title of the Article	Author(s):	Pub. Date:	Population	What science subjects(s) are mentioned:	Topic of the studies and their weighs:	What kind of outcome/conclusion does the article give:
178	New York High School Students Triumph in Prestigious Al Education Competition	N/A	2023	Both students and teachers/workers /researchers	Computer Science	Mainly discussing Al, hardly mentioning science learning	About students' future development
148	Teaching Data Science through Storytelling: Improving Undergraduate Data Literacy	You Li, Ye Wang, Yugyung Lee, Huan Chen, Alexis Nicolle Petri and Teryn Cha	2023	Only students/learners	Computer Science	Basically discussing science learning. with a small amount of mention of Al	About students' future development
25	Students' perceptions of using ChatGPT in a physics class as a virtual tutor	Lu Ding. Tong Li, Shilyan Jiang and Albert Gapud	2023	Only students/learners	Physics	The two topics' appearances are relatively equally	Concerns about the technical deficiencies of AI; Opinion(s) to a specific kind of AI

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4. Significance

The findings contribute significantly to understanding trends and patterns in existing research on the role of AI in university science education. The gaps under this research theme suggest that current research is simply insufficient to address the research question, especially in an international context. This highlights the urgent need for a more thorough investigation of whether AI truly enhances students' educational experience in science disciplines.

Existing literature tends to underestimate how AI affects student learning in science [10]. Therefore, future research should explore how students can effectively use AI tools to help them with their science education, including how AI can improve learning methods and support the research process. For instance, concerns regarding the possibility that students may use AI in their assignments and exams raise doubt about the validity of their learning experience. It’s noted that a great deal of current research mostly employs qualitative techniques, such as interviews, to gather different groups of people’s opinions of AI in science education [11]. Given that all of these are important, longitudinal studies that monitor the long-term impacts of AI on science learning outcomes are markedly lacking. This analysis aims to broaden the understanding of artificial intelligence’s function in science education, and it’s promising that this will encourage more research to identify and gradually resolve these limitations, leading to a greater awareness of AI’s effects on university science learning.

5. Conclusion

Before truly starting the result part, it’s important to know that the goal here was to understand the trends and patterns in AI’s application to science teaching at universities. Despite reading all 255 articles, the majority of which focused on how AI affected advanced science education for learners, very little of them explicitly answered the research question. Only less than 20 percent of the research passed the full-text screening process, and these studies mostly addressed the ways in which AI might benefit students’ learning in science-related fields like Computer Science, Physics, Chemistry, and Mathematics. This implies that although artificial intelligence is becoming increasingly popular in the field of education, almost nothing is deeply known about how it is used or how it affects university-level science learning.

Furthermore, most of the screened studies did not provide direct answers and perspectives to the research questions. Many studies either studied education broadly without specifically emphasizing how AI can facilitate science learning or discussed AI in a general context and failed to elaborate on its role in supporting students learning science subjects [12]. A large amount of research focused on teachers’ opinions or the incorporation of AI into teaching methods rather than on the exact influence on students' learning outcomes. As a result, a mere nine studies—less than one-fifth of the total number of papers in the review—made it to the extraction step, and of these, none offered thorough responses to the research objectives. This implies that there is a lack of details in the literature currently available about the use of AI to science education, particularly when it comes to the perspectives of the students.

Despite the limited amount of studies that reached the extraction stage, these articles still provide valuable insights for all of us into the role of AI in enhancing students’ learning experiences, as shown in Figure 2. Two of them specifically investigated the influences of AI on students’ performance by focusing on aspects such as knowledge acceptance and learning outcomes [1]. On the other hand, 6 other studies took a more comprehensive approach, looking at how AI can impact students’ future career choice and support their critical skills related to science learning.

Furthermore, Selwyn emphasized significant apprehensions regarding the constraints of artificial intelligence technology, namely with information veracity and matters pertaining to academic integrity [13]. Viewing these results as a whole, they indicate that though there is some kind of conclusion about the potential advantages and issues of AI in scientific learning, there is a clear absence of the existing research that thoroughly examines this link. This gap underlines the need for further studies, which should be addressed in the future.

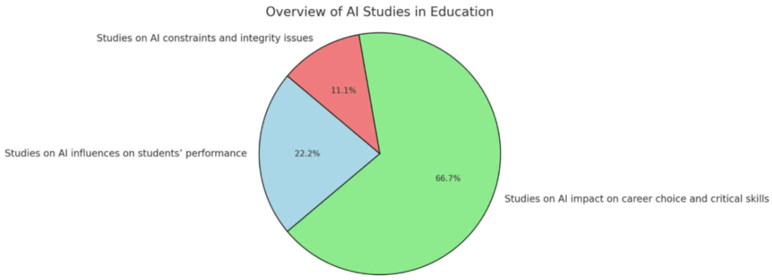

Figure 2: The distribution of studies on AI's role in education

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