

Integration of Artificial Intelligence (ChatGPT) into Science Teaching and Learning

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Article Info	Abstract
Article History Received: December 2024 Revised: January 2025 Published: March 2025	The integration of artificial intelligence (AI) into science education is transforming teaching and learning by offering innovative solutions to complex challenges. This study aims to review current trends in AI utilization, particularly ChatGPT, and explore its potential to improve problem-solving in science education. A systematic literature review was conducted using PRISMA guidelines, complemented by experiential exploration and qualitative insights from a thermodynamics lecturer. The findings highlight AI's ability to provide accurate explanations, generate diverse educational materials, and support interactive learning. However, limitations were identified, including inaccuracies in handling advanced or ambiguous problems and the potential for overreliance by students. Technical and ethical challenges, such as infrastructure requirements, educator preparedness, and concerns about bias, were also noted. These limitations underscore the importance of human oversight and critical evaluation of AI-generated content. The study recommends enhancing AI's contextual understanding, visualization capabilities, and adaptability to individual learner needs. By harmonizing AI-driven innovations with traditional teaching methods, educators can leverage these tools to create inclusive and effective learning environments, advancing the transformative potential of AI in science education.
Keywords Artificial intelligence; Science education; ChatGPT; Problem-solving; Personalized learning	
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INTRODUCTION

The integration of artificial intelligence (AI) technologies in education is expanding rapidly, driven by their ability to enhance learning experiences and outcomes. In science education, AI tools present innovative approaches to addressing educational challenges, enabling more tailored and effective learning methods. By supporting problem-solving activities, AI fosters the development of critical thinking and analytical skills essential for comprehending scientific principles and methodologies. Recent progress in AI has resulted in

advanced educational tools that adapt to individual learning needs, provide real-time feedback, and create customized learning pathways.

AI applications in science have demonstrated remarkable capabilities, particularly in problem-solving contexts. Machine learning, a branch of AI, has been applied in diverse scientific domains, such as mechanical engineering, solid-state materials, and condensed matter physics, as elaborated in subsequent discussions. These applications highlight AI's capacity to process complex datasets and extract insights, enhancing problem-solving efficiency. For instance, Schmidt et al. (2019) showcased AI's role in predicting material properties in solid-state science, accelerating discoveries and design innovations. Similarly, Cui et al. (2020) illustrated how AI improves diagnostic accuracy and treatment planning in medical imaging and radiation therapy. Furthermore, Bedolla et al. (2021) emphasized AI's utility in condensed matter physics by identifying phase transitions and explaining intricate physical phenomena.

The adoption of AI tools in scientific problem-solving marks a significant shift in addressing persistent challenges in the field. Traditional methods often involve extensive theoretical modeling and experimental validation, which can be time-consuming and resource-intensive. AI introduces a new paradigm by efficiently analyzing large datasets, identifying patterns, and expediting solutions. Carrasquilla (2020) highlighted AI's ability to uncover previously undetectable patterns in complex data through advanced computational methods. Additionally, AI's capacity to generalize learned information to novel scenarios enhances its value in scientific research. Adams and Wieman (2007) also underscored technology-driven tools as effective mechanisms for evaluating students' problem-solving processes, offering immediate and insightful feedback.

The integration of AI into scientific disciplines has ushered in a new era of research and innovation. Despite its potential, the adoption of AI technologies remains challenging. A major issue lies in the gap between AI's theoretical capabilities and practical applications across various scientific fields. This disparity often stems from a lack of interdisciplinary collaboration, which is critical for the successful implementation of AI. Moreover, integrating AI into science education presents unique challenges, particularly in adapting pedagogical methods to effectively incorporate AI-driven tools and techniques.

Interdisciplinary collaboration is pivotal for bridging the gap between AI's theoretical potential and practical implementation. Research indicates that interdisciplinary approaches can foster innovative solutions but also face obstacles such as differing disciplinary cultures and communication styles (Oey et al., 2020; Liu et al., 2021). For instance, Liu et al. noted that not all research teams benefit equally from interdisciplinary collaboration, underscoring the need for tailored strategies that account for the specific dynamics of different research groups. Similarly, the cognitive science community has expressed concerns regarding the effectiveness of interdisciplinary collaboration, noting that while increasingly common, it remains fraught with challenges (Oey et al., 2020).

Furthermore, the complexity of integrating AI into scientific research is heightened by the demand for researchers to possess a diverse skill set spanning multiple disciplines. The rapid evolution of AI technologies requires scientists to not only master their respective fields but also develop expertise in data science, machine learning, and computational methods (Mardiani, 2023; Kusters et al., 2020). This broad skill requirement can pose barriers, particularly for researchers from traditional scientific backgrounds who may lack training in these areas. Consequently, fostering an environment that promotes interdisciplinary learning and collaboration is essential to maximize AI's potential in scientific research.

In science education, the integration of AI introduces its own set of challenges. Educators must adapt their teaching methodologies to incorporate AI-driven tools and techniques, which can be daunting. For instance, Alshorman (2024) explored the readiness of science teachers to employ AI in classrooms, emphasizing the need for professional development and support to effectively integrate these technologies into teaching practices. Other researchers echo this sentiment, highlighting the importance of equipping educators with the skills and knowledge necessary to navigate AI's complexities in education (Akram et al., 2022; Kumar & Worsley, 2023). Additionally, implementing AI in education raises concerns regarding equity and access. Not all students have equal access to the resources and technologies required to engage with AI-driven learning tools, potentially exacerbating existing educational inequalities (Hamdan, 2024). Thus, educational institutions must prioritize equitable access to AI resources and provide comprehensive training for educators to ensure all students benefit from these advancements.

The challenges associated with integrating AI into science education are not solely technical but also encompass ethical considerations. As AI technologies become increasingly prevalent in educational settings, addressing their ethical implications is critical. This involves ensuring that AI systems are transparent, accountable, and free from biases that might negatively affect students' learning experiences (Saraiva, 2024; Luk, 2024). Educators must be prepared to engage in discussions on the ethical dimensions of AI and its societal impact, fostering critical thinking skills in students as they navigate these complex issues.

This paper systematically reviews the integration of AI as a tool for science problem-solving, with a particular focus on educational applications and practical implementations. It aims to address the lack of a holistic framework that consolidates these diverse applications into a cohesive model. By reviewing existing literature and incorporating personal experiences with AI tools such as ChatGPT, this study explores the potential of AI to create interactive and personalized learning environments that enhance student engagement and problem-solving skills.

Research Questions

1. What are the recent advances and trends in the use of AI tools, particularly ChatGPT, in science teaching and learning, and what are the identified benefits and challenges of integrating these technologies into science education?

2. How can AI tools, such as ChatGPT, enhance the development of problem-solving skills in science education, particularly in addressing complex scientific challenges effectively?

Research Objectives

1. To review current literature trends: The research aims to analyze recent advancements and trends in utilizing AI tools, particularly ChatGPT, in science teaching and learning. By examining a range of academic sources, the study highlights the benefits and challenges of integrating AI technologies into science education.
2. To explore AI's potential in enhancing problem-solving skills: The study investigates how AI tools can contribute to developing problem-solving skills within the context of science education. This includes examining personal experiences, such as employing ChatGPT, to address complex scientific challenges effectively.

Study Novelty

The novelty of this study is rooted in its dual focus on evaluating current trends in AI tool utilization, specifically ChatGPT, and exploring their potential to enhance problem-solving skills in science education. Unlike prior studies that primarily highlight theoretical capabilities or technical advancements, this research provides a holistic perspective by integrating a comprehensive literature review with practical insights derived from personal experiences. This combination offers a deeper understanding of how AI tools can address complex scientific challenges effectively while contributing to the broader context of science teaching and learning.

A defining aspect of this study is its examination of personal experiences using ChatGPT to solve intricate scientific problems. By documenting real-world applications, this research bridges the gap between AI's theoretical potential and practical implementation in educational contexts. It explores how tools like ChatGPT can foster critical thinking and analytical skills by adapting to diverse learner needs, delivering personalized guidance, and offering immediate feedback. This focus on experiential learning sets the study apart, as it demonstrates AI's tangible impact on developing problem-solving skills, aligning closely with the overarching goal of enhancing science education outcomes.

Additionally, the study contributes novel strategies for effectively integrating AI tools into science education practices. These strategies are designed to assist educators and students in leveraging AI technologies to improve engagement and learning efficiency. The research advocates a balanced approach, emphasizing the need to harmonize AI-driven innovations with traditional teaching methodologies. This ensures that AI's transformative potential is maximized while addressing challenges related to accessibility, equity, and ethics.

METHODS

This study utilized a multi-method approach to comprehensively explore the role of AI tools, specifically ChatGPT, in enhancing problem-solving skills in science education. The methodology was divided into two primary components: a systematic literature review and an experiential exploration of ChatGPT in practical educational settings.

Systematic Literature Review

Scope and Search Strategy

A systematic literature review was conducted to analyze recent advancements and trends in AI applications within science education. This review adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure a structured and reproducible process. The primary data source was the SCOPUS database, with searches performed using the keyword "AI in Science Education." To capture the most relevant and recent developments, the review focused on articles published between January 2023 and December 2024.

Selection Criteria

The selection process consisted of four stages: identification, screening, eligibility, and inclusion. During the identification stage, research articles relevant to AI in science education were retrieved using predefined keywords. The screening stage involved applying inclusion criteria, such as focusing on journal articles and conference proceedings written in English. Articles outside the scope of science education were excluded to maintain the study's relevance.

In the eligibility stage, each document was manually reviewed to ensure alignment with the study's objectives. This involved evaluating whether the articles specifically addressed the integration of AI tools, such as ChatGPT, in teaching and learning contexts. Articles that did not meet these criteria were excluded. The final inclusion stage involved an in-depth analysis of the selected articles, which were thoroughly examined to extract insights into how AI technologies contribute to problem-solving and science learning outcomes.

Data Extraction and Analysis

Key information, including author details, study objectives, and findings, was systematically extracted from the selected articles. The extracted data were analyzed to identify patterns and trends in AI applications, with particular attention to their impact on problem-solving skills. This analysis provided a theoretical foundation for understanding the capabilities and limitations of AI tools, aligning the findings with the study's objectives.

Experiential Exploration of ChatGPT

Design and Implementation

The second component of the methodology involved a hands-on exploration of ChatGPT's potential in solving science problems. This exploration was designed to assess ChatGPT's capabilities in addressing both simple and complex challenges within thermodynamics, a core area of science education. A series of thermodynamics problems were posed to ChatGPT, and its responses were meticulously evaluated for accuracy, coherence, and clarity. Each interaction was documented, with a focus on identifying ChatGPT's strengths and limitations as a problem-solving tool. This practical exploration was critical for understanding how AI tools can be effectively employed in real-world educational settings to enhance students' analytical and critical thinking skills.

Qualitative Insights from Educators

To complement the experiential findings, qualitative data were gathered through an interview with a lecturer from a leading Southeast Asian university. The lecturer, with extensive experience teaching thermodynamics science courses and using ChatGPT as a teaching aid, provided valuable insights into the practical application of AI tools in science education. The interview was transcribed and analyzed to identify recurring themes, such as the efficacy of AI in supporting student learning and the challenges associated with its integration.

Synthesis and Integration

The findings from the literature review and experiential exploration were synthesized to create a comprehensive understanding of AI's role in science education. The synthesis involved comparing theoretical insights from the reviewed articles with practical findings from the hands-on use of ChatGPT. This integration provided a balanced perspective, highlighting both the potential and limitations of AI tools in enhancing problem-solving skills.

Recommendations for Practice

Based on the combined findings, practical strategies were proposed to guide educators and students in effectively incorporating AI tools into their teaching and learning processes. These recommendations emphasized leveraging ChatGPT's ability to provide step-by-step problem-solving guidance while mitigating its limitations through strategies such as cross-referencing with traditional resources and using AI as a supplementary tool. The study advocated for a balanced approach, harmonizing AI-driven innovations with established pedagogical practices to optimize learning outcomes.

RESULTS AND DISCUSSION

Using the PRISMA methodology, a systematic literature review was conducted to analyze recent advancements and trends in AI applications within science education. During the identification stage, 2,639 documents were retrieved, with their distribution illustrated in Figure 1. As shown in Figure 1(a), the number of publications increased significantly over time, reaching a peak of 1,044 documents in 2024. This exponential growth reflects the growing interest and recognition of AI's transformative potential in the field of science education.

The types of documents identified are shown in Figure 1(b). Journal articles represented the largest proportion (39.1%), followed by conference papers (37.5%). These document types dominate the field, as journal articles provide detailed insights into comprehensive research findings, while conference papers highlight emerging developments. Other types of documents, such as reviews (9.2%) and book chapters (5.6%), played a smaller yet important role in contributing broader perspectives on AI's integration in science education.

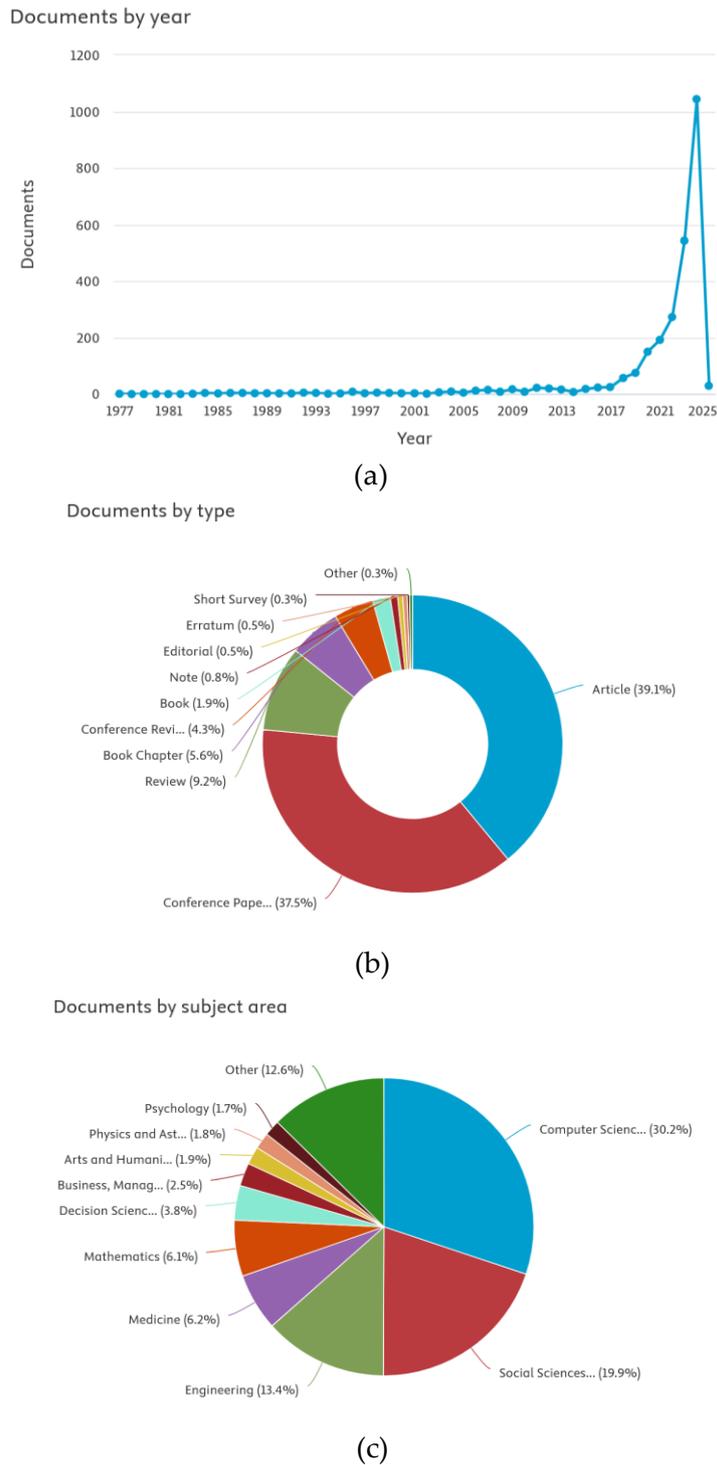


Figure 1. Distribution of identified documents: (a) documents by year, (b) documents by type, and (c) documents by subject area

Figure 1(c) highlights the subject areas of these documents, with computer science leading the distribution (30.2%), emphasizing its critical role in developing and applying AI technologies. Social sciences (19.9%) and engineering (13.4%) also featured prominently, reflecting interdisciplinary applications of AI across various fields. Smaller but significant

contributions from mathematics (6.1%), medicine (6.2%), and physics and astronomy (1.8%) further illustrate AI's versatility in addressing domain-specific challenges.

After applying screening criteria, including relevance to science education and English-language journal articles or conference proceedings, 843 documents were selected. Following manual evaluation during the eligibility stage, 121 documents were shortlisted based on alignment with the study's objectives. Finally, 14 documents met the inclusion criteria for detailed analysis. These 14 documents provided key insights into the benefits and challenges of using AI in science education.

The analysis of the final 14 documents identified recurring themes, focusing on the benefits and challenges of integrating AI tools into science education.

Benefits of Using AI in Science

The incorporation of AI technologies has profoundly impacted science education, revolutionizing teaching methods and advancing research practices. One of AI's major contributions lies in its ability to assist with the development and enhancement of educational materials. Educators employing AI tools, such as ChatGPT-4, have experienced notable advancements in crafting lesson plans, particularly for historical experiments like those conducted by Thomson, Millikan, and Rutherford. These tools have proven effective in structuring lessons, suggesting instructional resources, providing pedagogical strategies, and generating assessments, enabling educators to offer personalized and detailed instruction to their students (Clark et al., 2024). Similarly, AI integration has expanded to address complex and specialized scientific topics. For example, Italian science curricula have successfully incorporated AI-powered platforms alongside microcontroller development boards to teach advanced subjects such as climate change, space exploration, and Einstein's theory of relativity. These previously underrepresented topics are now more engaging and accessible, deepening students' understanding and interest in contemporary scientific challenges (Piccione et al., 2024).

Beyond lesson planning, AI has also shown its utility in practical applications and problem-solving scenarios. AI models, like GPT-3.5-turbo, have been assessed for their capability to answer exam-style science questions at varying educational levels. The models performed exceptionally well at the general certificate of secondary education (GCSE) level, though their proficiency diminished with more advanced queries. This indicates AI's significant potential for supporting foundational science education while emphasizing the need for further refinement to tackle higher-level scientific problems (Yeadon & Hardy, 2024). Additionally, tools such as Tinkercad have enabled students to model and explore electric circuits in virtual environments, facilitating direct interaction with physical laws and phenomena. This hands-on digital approach has proven particularly valuable in science subjects requiring experimentation and observation, as it helps streamline the learning process and improve student comprehension (Borisova et al., 2023).

AI's influence extends to scientific research, where it has been instrumental in solving complex problems and fostering interdisciplinary collaboration. The NSF AI Institute for

Artificial Intelligence and Fundamental Interactions (IAIFI) exemplifies the integration of AI with foundational scientific principles. By leveraging AI's capabilities, researchers at the institute have addressed challenging issues in physics and other fields, enriching the scientific community's knowledge base and creating a collaborative environment between disciplines (Thaler et al., 2024). AI has also significantly advanced quantum computing (QC) by improving the control of quantum systems through the development of sophisticated algorithms. These advancements have enabled deeper insights into quantum principles and accelerated the discovery of new quantum applications (Zhu & Yu, 2023).

In the educational realm, AI has demonstrated its potential for generating synthetic datasets to support the development of science concept inventories, such as the Force Concept Inventory (FCI). By simulating student responses, these datasets help educators identify common misconceptions and design targeted interventions to improve understanding of fundamental scientific concepts (Kieser et al., 2023). This approach ensures that educators have access to scalable tools for enhancing science instruction and addressing student learning gaps.

In qualitative research, AI has further contributed by enabling novel analytical methods. Computational grounded theory (CGT), for instance, integrates AI's pattern recognition capabilities with human interpretation to analyze large datasets. This approach provides a reproducible and scalable means of examining educational outcomes and understanding student problem-solving behaviors (Tschisgale et al., 2023). In addition, physics-informed machine learning (PIML) has merged physical laws with machine learning models to address complex scientific problems. By embedding physical principles into AI algorithms, PIML ensures that the models produce accurate and interpretable results, improving their reliability and extending their applicability in scientific research (Muther et al., 2023).

The diverse applications of AI in science education and research reflect its transformative potential to drive innovation and improve teaching practices. From fostering deeper student engagement to solving intricate scientific challenges, AI tools have become indispensable in modern education. Research highlights the broad-ranging advantages of these technologies, including their ability to personalize learning, accelerate discoveries, and support interdisciplinary collaborations. However, as AI continues to evolve, ongoing efforts are needed to refine these tools, address ethical considerations, and ensure equitable access to their benefits. These efforts will maximize AI's impact on both education and research, paving the way for a more innovative and inclusive scientific landscape (Ding et al., 2023; Liang et al., 2023; Mahligawati et al., 2023; Wang et al., 2023; Rico et al., 2023).

Challenges of Using AI in Science

While AI offers numerous benefits to science and science education, it also presents significant challenges and limitations that require careful consideration. One of the primary concerns is the accuracy and reliability of AI-generated content. For instance, research has revealed that while GPT-3.5-turbo performed well on simpler tasks, such as answering general certificate of secondary education (GCSE)-level science questions, its performance

diminished significantly with more advanced problems, such as university-level and A-Level questions. The model achieved an average score of 83.4% on GCSE-level questions but only 37.4% on university-level problems, highlighting its limited capacity to handle complex scientific inquiries (Yeadon & Hardy, 2024). Similarly, as an assessment tool, AI demonstrated inconsistencies, with only a 50.8% concordance rate with human graders when marking straightforward questions like multiple-choice ones. Such inaccuracies raise concerns about the reliability of AI for providing accurate evaluations and meaningful feedback to learners (Yeadon & Hardy, 2024).

Another notable limitation is AI's inability to produce effective visual aids, which are critical in science education for illustrating concepts that require diagrams, graphs, or other graphical representations. Although tools like ChatGPT-4 excel at crafting lesson plans and delivering textual explanations, they fail to create visual materials that are essential for a comprehensive learning experience (Clark et al., 2024). In practical applications, AI has also shown difficulty solving under-specified, real-world problems. For example, ChatGPT's accuracy in addressing such challenges was only 8.3%, demonstrating its struggle to develop accurate models of the physical world and account for incomplete or ambiguous data (Wang et al., 2023). This shortcoming is particularly concerning for STEM education, where real-world problem-solving skills are fundamental.

Trust and overdependence on AI tools represent additional challenges. Despite inaccuracies in AI-generated responses, students often place unwarranted trust in these outputs, leading to misconceptions and overreliance on AI for solutions (Ding et al., 2023). This is problematic because models like ChatGPT frequently produce answers that appear plausible but are incorrect, encouraging students to accept flawed information without verification. Moreover, AI tools often generate verbose and irrelevant responses, further complicating their utility in education. For example, ChatGPT occasionally introduces unconventional methods not included in standard curricula, along with verbosity and calculation errors, particularly in basic arithmetic, which can confuse students rather than aid their understanding (Yeadon & Hardy, 2024).

The integration of AI into science education also brings technical, logistical, and ethical challenges. Substantial technical infrastructure is required to implement AI technologies effectively, but such resources may not be universally available, particularly in underfunded institutions (Mahligawati et al., 2023). Additionally, teachers need extensive training to effectively utilize AI tools in the classroom, which poses a challenge given the rapid evolution of AI technologies and educators' already demanding workloads (Mahligawati et al., 2023). Data privacy and ethical considerations further complicate AI adoption in education. Using AI in educational settings must comply with privacy laws and address ethical concerns such as algorithmic biases and fairness in decision-making processes (Mahligawati et al., 2023).

In advanced applications, such as quantum computing (QC), AI has shown promise but remains unreliable in some aspects. For example, while AI has been employed to improve the control of quantum systems, it has not yet reached the level of dependability required for fully

automated operation. This limitation hinders the broader application of AI in QC research and education (Zhu & Yu, 2023). Similarly, AI has been used to generate synthetic datasets for educational purposes, such as the Force Concept Inventory (FCI). However, these datasets often fail to capture the diversity and variability expected from real student responses, reducing their effectiveness in simulating realistic educational scenarios (Kieser et al., 2023).

Overall, while AI offers substantial advantages for science education and research, its disadvantages must be carefully managed to unlock its full potential. Accuracy and reliability remain key concerns, particularly for advanced and real-world applications. The inability to produce visual aids and address under-specified problems limits its effectiveness in STEM education, while overreliance on AI-generated outputs risks fostering misconceptions among students. Moreover, challenges related to technical infrastructure, teacher preparedness, and ethical considerations further complicate AI's integration into educational settings. Addressing these limitations requires a balanced approach that includes improving AI technologies, providing training for educators, ensuring equitable access to resources, and fostering critical thinking to help students effectively engage with AI tools. By tackling these challenges, AI's transformative potential in science education can be more fully realized.

Personal Experience Using AI Tools

The performance of ChatGPT in addressing thermodynamics questions was systematically evaluated by analyzing its responses to various problem scenarios, emphasizing both its strengths and limitations in problem-solving. Previous research by Mustofa et al. (2024) demonstrated that ChatGPT performed well when solving both simple and complex thermodynamics problems, often providing correct and accurate answers. However, the study also revealed significant limitations. When ChatGPT was tasked with solving problems requiring accurate interpretation of graphical data, it frequently generated incorrect responses due to its inability to process visual elements effectively (Mustofa et al., 2024). Building on this, the current study reassessed ChatGPT's accuracy by presenting thermodynamics questions in the form of images. The problem descriptions used in this evaluation are detailed below.

Commands to ChatGPT: *Solve the following problem using Thermodynamic's Laws: How much is the work output per cycle for the thermodynamic cycle in the attached figure? Provide detailed steps in solving this problem.*

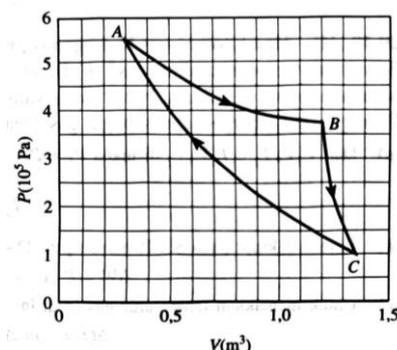


Figure 2. PV diagram for thermodynamic process analysis in an ideal gas system

The correct answer to the problem is 100 kJ. However, ChatGPT provided an incorrect response of -1×10^3 Joules. This highlights a notable limitation of the AI in accurately solving thermodynamic problems, particularly when precise calculations are required. ChatGPT's responses to the thermodynamics questions are illustrated in Figure 3, showcasing both its computational errors and the challenges it faces in handling such scientific scenarios.

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Solve the following problem using Thermodynamic's Laws:

How much is the work output per cycle for the thermodynamic cycle in the attached figure?
Provide detailed steps in solving this problem

🌀 To calculate the work output per cycle for the thermodynamic cycle shown in the attached figure, we need to find the area enclosed by the cycle on the Pressure-Volume (P-V) diagram. This area represents the net work done by the system over one complete cycle.

Here are the steps to find the work output per cycle:

1. **Identify the Cycle Shape:** The cycle shape in the P-V diagram consists of three segments: from point A to B, from B to C, and from C back to A.
2. **Estimate the Area under Each Segment:**
 - **Segment A to B:** This segment appears as a curve on the graph. Approximate the area under this curve by considering it as part of a triangle or by numerical integration if the functional form is known.
 - **Segment B to C:** This segment is a vertical line. Since it's a vertical line on a P-V diagram, the work done (area under the curve) is zero because the volume does not change.
 - **Segment C to A:** This segment is also a curve. Again, you can approximate this as part of a triangle or use numerical integration for more accuracy.
3. **Calculate Approximate Areas:**
 - **Triangle for A to B:**
 - Base (Volume change, ΔV) = Volume at B - Volume at A = $1 \text{ m}^3 - 0 \text{ m}^3 = 1 \text{ m}^3$
 - Height (Pressure change, ΔP) = Pressure at A - Pressure at B = $5 \times 10^5 \text{ Pa} - 1 \times 10^5 \text{ Pa} = 4 \times 10^5 \text{ Pa}$
 - Area $\approx 0.5 \times \text{Base} \times \text{Height} = 0.5 \times 1 \times 4 \times 10^5 = 2 \times 10^5 \text{ Joules}$
 - **Triangle for C to A:**
 - Base (Volume change, ΔV) = Volume at A - Volume at C = $0 \text{ m}^3 - 1.5 \text{ m}^3 = -1.5 \text{ m}^3$
 - Height (Pressure change, ΔP) = Pressure at C - Pressure at A = $1 \times 10^5 \text{ Pa} - 5 \times 10^5 \text{ Pa} = -4 \times 10^5 \text{ Pa}$
 - Area $\approx 0.5 \times \text{Base} \times \text{Height} = 0.5 \times (-1.5) \times (-4 \times 10^5) = 3 \times 10^5 \text{ Joules}$
4. **Calculate Total Work:**
 - Total work done per cycle = Area under A-B + Area under B-C + Area under C-A = $2 \times 10^5 + 0 - 3 \times 10^5 = -1 \times 10^5 \text{ Joules}$.

The negative sign indicates that the net work is done on the system rather than by the system. In the context of a thermodynamic cycle like this, which typically represents engines or other mechanical devices, a positive value for the work would be expected if the system is doing work on the surroundings. This result suggests that either the cycle or the approximations may need to be reevaluated for physical consistency or corrections in estimation.

If a more precise calculation is needed, details regarding the functional form of the curves or a numerical integration technique might be required.

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Figure 3. ChatGPT's responses to the thermodynamics questions

Previous studies have indicated that while ChatGPT has the potential to revolutionize education, it also has limitations and may produce errors, potentially creating additional challenges (Araújo & Saúde, 2024). Recognizing these limitations is crucial for educators to effectively integrate ChatGPT into their teaching practices (ElSayary, 2024).

Insights from personal experiences with ChatGPT in solving science problems were further enriched by an interview with a thermodynamics lecturer. The interview provided valuable perspectives on the tool's practical applications and challenges, and a summary of the findings is presented in Table 1.

Table 1. Insights from the interview on the use of ChatGPT in teaching thermodynamics

No	Interviewer	Lecturer responses
1.	What were your initial experiences using ChatGPT in Thermodynamics teaching?	“My first experience using ChatGPT for teaching Thermodynamics was insightful. I utilized the tool to create examples and simplify complex topics such as entropy and the laws of thermodynamics. ChatGPT’s ability to break down intricate ideas made it easier for students to understand these concepts.”
2.	What motivated you to use ChatGPT as an instructional tool?	“The main reason for choosing ChatGPT was its ability to provide instant, diverse explanations. It acts as a supportive resource, responding to student questions in real time and enhancing engagement. Its flexibility in delivering text summaries, detailed analyses, and examples makes it a highly effective teaching aid.”
3.	How does ChatGPT support the explanation of complex Thermodynamics concepts?	“ChatGPT helps by breaking down complex ideas into simpler parts. For instance, when explaining the second law of thermodynamics, it uses analogies and real-world examples to make the concept more relatable. Its ability to handle follow-up questions allows for a deeper understanding through interactive discussion.”
4.	Have you faced any challenges when using ChatGPT in Thermodynamics education? How were they addressed?	“Yes, there are limitations. Sometimes ChatGPT provides oversimplified answers or lacks the context necessary for advanced comprehension. To manage this, I review its responses and provide additional clarifications. I also encourage students to critically assess the tool’s answers and ask for further explanations when needed.”
5.	How does ChatGPT assist in designing assignments or quizzes?	“ChatGPT is helpful in creating a variety of questions covering different aspects of thermodynamics. It generates both theoretical and numerical questions, ensuring a well-rounded assessment. Additionally, it offers detailed solutions and explanations that I use to guide students in their problem-solving process.”

No	Interviewer	Lecturer responses
6.	Do you think ChatGPT can replace certain aspects of traditional teaching? Why or why not?	“While ChatGPT enhances specific aspects of teaching, it cannot replace traditional methods. Personalized guidance and human interaction are crucial for effective learning. ChatGPT is a valuable supplementary tool, but it cannot replicate the mentorship, emotional support, or tailored feedback provided by human educators.”
7.	What are your hopes for the future of AI tools like ChatGPT in education, especially for Thermodynamics?	“I hope tools like ChatGPT will evolve to offer more context-aware educational content. Features like personalized learning pathways and the ability to adapt to individual student needs would be particularly valuable. For Thermodynamics, improved visualization capabilities and real-world simulations would greatly enhance the teaching and learning process.”

The evaluation of ChatGPT's responses to thermodynamics questions, combined with insights from an interview with a thermodynamics lecturer, provided valuable perspectives on the application of AI in education, especially in teaching complex topics like thermodynamics. Table 1 highlights ChatGPT's ability to deliver accurate and clear explanations for various concepts, including the laws of thermodynamics and entropy. Its capability to generate illustrative examples and simplify complex topics helped students grasp challenging material more effectively. However, the lecturer pointed out that, despite its proficiency in breaking down intricate concepts into simpler parts, ChatGPT occasionally produced overly simplified answers or omitted crucial context-specific details necessary for higher-level understanding. This shortcoming required educators to review and supplement its outputs to ensure accuracy and completeness. Previous research supports these findings, with ChatGPT demonstrating both strengths and areas of concern (Sallam, 2023). While it excelled in natural, conversational exchanges (Xu et al., 2024), the quality of its information varied depending on the context (Fahy et al., 2024).

One key reason for utilizing ChatGPT as an educational tool is its ability to provide instant and diverse explanations, enhancing interactivity and engagement in the learning process. By addressing student questions in real-time, ChatGPT offers flexible information delivery through text summaries, in-depth explanations, and practical examples (Tlili et al., 2023). This interactive approach complements traditional teaching methods, allowing students to engage in dynamic dialogues that reinforce understanding (Guha et al., 2024). Additionally, ChatGPT reduces the time educators spend on routine tasks, enabling them to focus on more creative and cognitively demanding aspects of instruction (Guha et al., 2024).

Another notable strength of ChatGPT lies in its ability to assist with designing assignments and quizzes. It can create a variety of questions covering diverse aspects of thermodynamics, including conceptual and numerical problems, ensuring comprehensive assessments of student knowledge. Moreover, ChatGPT can draft detailed solutions and explanations, providing educators with valuable resources to guide students through their

learning process. This functionality enhances instructional materials, making them more dynamic and engaging for learners. However, ChatGPT's limitations in mathematics, occasional conceptual inaccuracies, and errors in citation highlight the need for caution (Tyson, 2023). Educators must play an active role in integrating such tools into instruction, fostering critical thinking and analytical skills among students (Hutchison, 2024).

Despite its advantages, the interview identified several challenges in using ChatGPT for teaching thermodynamics. The most significant issue was its occasional production of overly simplified or contextually incomplete responses. To mitigate this, educators should consistently review and expand upon ChatGPT's outputs, providing additional examples and explanations tailored to their students' needs (Eysenbach, 2023). Encouraging students to critically assess ChatGPT's responses and seek clarification when necessary is also crucial for fostering independent thinking (Eysenbach, 2023).

While ChatGPT can enhance many aspects of traditional teaching, the lecturer emphasized that it cannot fully replace the human interaction and personalized guidance critical to effective education. ChatGPT serves as a supplementary resource, providing additional instructional support (Harry, 2023; Song, 2024; Wang et al., 2023), but it lacks the ability to deliver the mentorship, emotional engagement, and nuanced feedback that only human educators can provide (Kucirkova & Leaton-Gray, 2023). These observations highlight the importance of integrating AI tools like ChatGPT within a broader educational framework rather than considering them as standalone replacements for traditional teaching methods.

Looking ahead, there are high expectations for the future development of AI technologies like ChatGPT in education. The lecturer expressed hope that such tools would become more advanced in generating context-specific educational content. Enhanced personalization, where AI can adapt to individual student needs and learning styles, would significantly improve their utility. In the context of thermodynamics, advancements in visualizing complex phenomena and simulating real-world scenarios could greatly enrich the learning experience, making abstract concepts more tangible and relatable.

In summary, ChatGPT shows significant promise in transforming science education, particularly in teaching thermodynamics. However, recognizing and addressing its limitations is critical to leveraging its full potential. By thoughtfully integrating AI tools and supplementing them with human expertise, educators can create more engaging, effective, and inclusive learning environments that benefit students at all levels.

CONCLUSION

The integration of artificial intelligence (AI) tools like ChatGPT into science teaching and learning presents transformative opportunities for improving educational outcomes and research practices. This study demonstrates that AI has the potential to personalize learning, enhance student engagement, and simplify complex scientific concepts, making them more accessible to learners. By combining systematic literature review insights and experiential analysis, the research highlights AI's ability to address diverse educational challenges, particularly in developing problem-solving skills and fostering analytical thinking. These

findings underscore AI's significant role in advancing science education through innovative applications that support both teaching and learning processes.

Despite these promising benefits, the study also reveals important limitations and challenges associated with AI's integration into educational contexts. Issues such as inaccuracies in responses, difficulty in handling advanced or under-specified problems, and the lack of effective visual aids necessitate a cautious approach. Additionally, reliance on AI tools requires educators to provide oversight, supplement AI outputs, and foster critical thinking among students to mitigate potential risks like overdependence or misinformation. Furthermore, challenges related to technical infrastructure, ethical concerns, and equitable access must be addressed to ensure the successful adoption of AI technologies in diverse educational settings.

To fully leverage the transformative potential of AI in science education, this study advocates a balanced approach that combines technological innovation with human expertise. Future advancements in AI tools should focus on improving accuracy, contextual understanding, and visualization capabilities to better support complex scientific topics. Moreover, enhancing the adaptability of AI to individual learner needs and equipping educators with the necessary skills and training will be critical. By thoughtfully integrating AI into traditional teaching methodologies, educators can create more effective, inclusive, and engaging learning environments, driving meaningful progress in science education.

LIMITATION

This study highlights several limitations in integrating AI tools like ChatGPT into science education. The most significant constraints include inaccuracies in AI-generated content, particularly when addressing advanced or under-specified problems, and the inability to produce effective visual aids crucial for STEM education. Additionally, AI's reliance on high-quality input data, limitations in context-specific understanding, and occasional oversimplifications present challenges for its broader applicability. Technical barriers, such as the need for robust infrastructure and educator training, further restrict accessibility, while ethical concerns regarding data privacy and algorithmic biases underscore the importance of careful implementation.

RECOMMENDATION

Future efforts should focus on enhancing AI tools' accuracy and contextual understanding, particularly in handling complex or ambiguous problems. Investments in educator training programs and equitable access to AI resources are essential for maximizing their impact across diverse educational settings. Additionally, integrating AI technologies with tools for visualization and simulation can significantly enhance their utility in STEM disciplines. Policymakers and institutions should also establish clear ethical guidelines to ensure transparency, accountability, and fairness, creating a balanced approach that supports both technological innovation and effective teaching practices.

Author Contributions

The authors have sufficiently contributed to the study, and have read and agreed to the published version of the manuscript.

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Conflict of interests

The authors declare no conflict of interest.

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