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Artificial Intelligence and Critical Thinking: A Systematic Review of Its Potential in Engineering Education

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ABSTRACT

BACKGROUND & CONTEXT

The education landscape of the 21st century is swiftly changing due to many factors, particularly the increasing use of Artificial Intelligence (AI). AI has already begun altering traditional pedagogical practices by creating enhanced learning environments that encourage innovative approaches to knowledge construction. At the same time, critical thinking which is the ability to analyze, evaluate, and synthesize material to form sound judgments, remains an essential skill in modern education. With AI becoming increasingly important in engineering education, it is crucial to understand how it can promote critical thinking among engineering students. Using the PRISMA framework, this study systematically reviews research from 2015 to 2025 on AI's effect on critical thinking.

PURPOSE OR GOAL

This study aims to investigate how AI supports the development of students' critical thinking skills, as well as the associated benefits and limitations, with a particular focus on applications in engineering education.

APPROACH OR METHODOLOGY

This study employs a systematic literature review (SLR) to analyse AI application in education which involves searching academic databases such as Scopus, IEEE Xplore, Web of Science and ScienceDirect. The relevant literature will be filtered using the PRISMA framework. The inclusion and exclusion criteria were applied to filter studies that provide insight into AI's role in fostering critical thinking skills.

OUTCOMES

The findings provide data-driven evidence on AI's impact on students' critical thinking skills, highlighting both benefits and limitations. The SLR method synthesizes insights from diverse studies, offering a comprehensive understanding of AI-enhanced education.

CONCLUSIONS

This study highlights the AI's transformative potential in education and its role in nurturing students' critical thinking skills. The findings offer insights into how AI-enhanced learning can improve educational outcomes and equip students with essential skills for the digital age.

KEYWORDS

Artificial Intelligence, Critical Thinking, Engineering Education.

Introduction

The educational field of engineering undergoes fundamental transformation because of AI technology which introduces innovative educational tools and methods that enhance learning while developing critical thinking abilities. The data-mining capabilities of AI technology allows students to create individual learning paths which enables them to study concepts and abstract ideas at their own speed and through their preferred learning approach (Chen et al.,2020). The customized learning approach delivers appropriate support and constructive feedback to students which strengthens their understanding of concepts while encouraging deeper exploration and cognitive development (Fu, Y, & Hiniker, A.,2025). AI-based tools according to Celik et al., (2024) enable students to develop their critical thinking abilities. Numerous research demonstrates that AI-based tools enable students to make academic decisions through judgment support particularly when they need help in solving problems or understanding complex materials (Melisa et al., 2025) and as personalized and adaptive learning environments responding to learners' individual needs and preferences (Kumar et al.,2023).

Considering the ongoing growth, it has called for a need to strive toward better quality in teaching and learning experienced in Malaysia. To guarantee that students are adequately equipped for the technological breakthroughs in the engineering area, the Ministry of Higher Education, for example, has acknowledged the significance of AI literacy and is attempting to integrate AI across universities in 2025 as mentioned in Malaysia International Science Council (Mohd Sharef, N.,2021). However, it also raises important challenges that require very particular problem-solving, creativity, and analytical accuracy in addressing them. These findings are particularly relevant to engineering education, where critical thinking is a core competency for problem-solving and innovation. AI tools, when integrated responsibly, can complement engineering pedagogy by fostering analytical reasoning and reflective decision-making among future engineers (Zawacki-Richter et al., 2019). As students continue to use more and more AI production platforms, the expected form of intellectual engagement is changing. The increasing numbers of students using AI raises fears regarding reliance by using them as solution that reduced time and opportunity for real in-depth inquiry and consequently, creating passive learning states (Bai, L., et al., 2023). Even though AI technologies hold the potential for establishing effectiveness, delivering personalized learning, and allowing data-driven decisions to be made, more research is needed regarding how they may shape students' critical thinking, a fundamental part of engineering competence (Roy, S., & Paul, S.K., 2023). Questions of inequality, privacy, accountability, and transparency need proper resolution so that the good outcome of the AI revolution in education is ascertained (Roy, S., & Paul, S.K., 2023). Hence, it is worth pondering about the implementation of appropriate measures that ensure responsible usage within academic environments (Sánchez-Ruiz, L. M., et al., 2023). Specifically, this study seeks to address the following research questions: (1) How artificial intelligence (AI) can enhance student's critical thinking skill? and (2) What are artificial intelligence (AI) benefits and limitation in modern education? By examining these dimensions, this study aims to contribute to the discourse on how AI can be aligned with the core educational goals of fostering independent, reflective, and adaptive students with essential skills for the digital age.

Background

A new dimension to learning and teaching has been achieved through the presence of artificial intelligence (AI) in the class, mainly in the construction of critical thinking abilities, which are one of the key in overcoming the challenges of the digital era. AI technologies are used in the construction of machine learning (ML) algorithms, which are implemented in interactive learning technologies. Therefore, idea generation, evaluation, and refining are possible when the research's applicability of the topic is being gauged on the content basis. The creative problem-solving methods and curiosity are aided by AI in classrooms by the use of machine

learning (ML) algorithms. Machine learning can be used in the prediction engine, which is part of the AI development, to prioritize learners' needs of the learning modules.

Based on numerous studies, AI offers a new form of learning, incorporating several new affordances and learning capabilities. For example, intelligent chat bots can evaluate students' thinking and enhance metacognitive awareness, while some AI-based tutoring system can modify task outcomes depending on a learner's performance, which can motivate students to interact with the content more deeply. In the digital age, there are many benefits to using AI for increasing critical thinking skills, including higher levels of motivation, increased student agency, and creating equitable access to great learning experiences across diverse educational and socioeconomic contexts. Yet there are significant disadvantages to heed, even with these upsides. Too much reliance on AI technologies raises troubling questions because it can detract from the development of self-regulated learning in students, when used carelessly. In addition, there are ethical issues related to algorithmic bias, data privacy, and the risk of dehumanizing education. These challenges point to a need for holistic approaches to integration that capitalize on AI's affordances while promoting the human aspects of pedagogy and critical discourse content.

To review the body of empirical and theoretical literature on the cited advantages and potential risks of AI, and how it can enhance critical thought, this study takes a systematic literature review (SLR) approach as described by the PRISMA. This literature review aims to build an understanding of any evidence base demonstrated in prior literature by synthesizing studies in a way that we can ensure AI is a legitimate means of fostering critical thinkers in a rapidly changing digital society. It is also hoped that it will inform future research and policy development regarding educational technology.

Methodology

This methodological approach used in this study included three section which is the search strategy, the data collection and inclusion and exclusion criteria.

Search Strategy

This study employs a systematic literature review (SLR) to analyze AI application in education from 2015 to 2025 which involves searching academic databases such as Scopus, IEEE Xplore, Web of Science and ScienceDirect. Utilizing these databases guarantees that the obtained data are from a reliable, influential, and peer-reviewed sources, which is essential for the validity and dependability of meta-analyses and systematic literature reviews. They are also renowned for their extensive citation analysis and indexing capabilities, which enable researchers to track a paper's relevance and significance over time providing essential resources especially when it is related to a cutting-edge studies like artificial intelligence. Once the relevant literature has been gathered, it will be filtered out by using the PRISMA framework. The inclusion and exclusion criteria were carefully applied to filter studies that provide insight into AI's role in fostering critical thinking skills

An extensive search using the Scopus, IEEE Xplore, Web of Science and ScienceDirect database and specific keywords yielded a total of 1,715 documents published between 2015 to 2025. This wide-ranging collection of research was carefully reviewed using the PRISMA framework. Applying this structured method helped ensure that the selected studies met high standards of quality and completeness. As a result, the process enabled the extraction of meaningful insights and supported the development of well-founded conclusions for the current research.

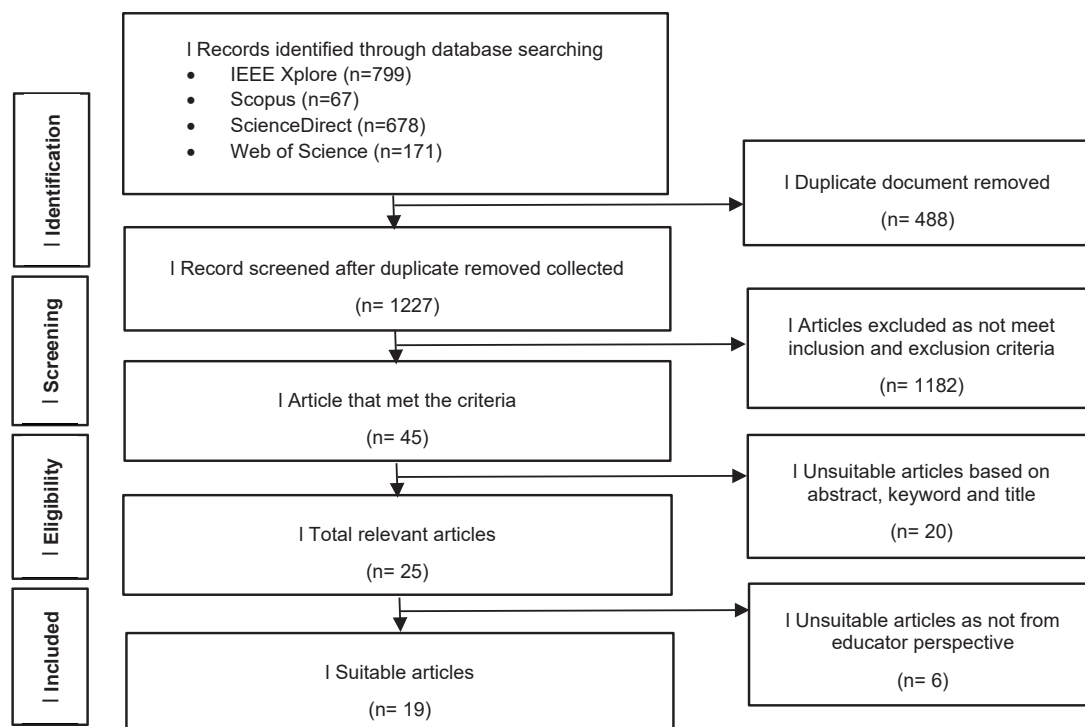


Figure 1: PRISMA Flowchart

Data Collection

This study aims to synthesize published articles that discuss AI in modern education and its role in developing critical thinking skills among engineering students. By using a keyword, it collects and analyze peer-reviewed articles related to the utilization of artificial intelligence in modern education from reliable academic databases. The primary sources include Scopus, Web of Science, IEEE Xplore, and ScienceDirect, which has high-impact journals and articles in the areas of educational technology and engineering subjects. The keywords "Artificial Intelligence in Education," "AI and Critical Thinking" and "AI in Engineering Education" are used to filter relevant studies published from 2015 to 2025. After that, the screening is based on the two major themes, which are the application of AI in educational settings and its role in enhancing critical thinking skills among students particularly in engineering contexts and the advantages and implications of AI in the digital age. This methodology employs a focused evidence-based approach to make sure the existing literature on this topical discourse and provide a framework for discussing the impact of AI on student critical thinking, highlighting the advantages and disadvantages of AI-enabled learning.

Inclusion and Exclusion Criteria for Selection of Publication

To ensure the reliability and validity of this study, a carefully structured inclusion and exclusion process was carried out, as detailed in Table 1. This systematic approach was necessary to identify the most relevant and credible sources that aligned with the research objectives. Additionally, to strengthen the credibility of the findings, a clear-cut set of quality indicators was applied. These measures directly contribute to the overall precision and integrity of the research.

Table 1: Inclusion and Exclusion Criteria

Inclusion	Exclusion
Research must relate to artificial intelligence (AI) and enhancement of critical thinking	Research did not relate to AI and enhancement of critical thinking
Research must relate to the benefits and limitation of AI in modern education	Research did not relate to the benefit and limitation of AI in modern education
Research must be published of the year 2015 to 2025	Research is published not in the year of 2015-2025
Research must be in English	Research is made in other language than English
Research article must be openly accessible in full version	Research article is not available and incomplete

1715 articles have been obtained from the online databases using the PRISMA method. 488 duplicate documents have been excluded during the identification process. From 1227 document that undergo screening process, 20 documents are excluded due to no relation of AI and critical thinking. Another 11 document are also excluded due to unavailability of English language and 1171 documents were not fully accessible. A total of 25 documents are assessed for eligibility but a total of 6 are discarded due to irrelevant literature. In-depth analysis involved developing objectives and formulating research questions to achieve the study's aims, resulting in 19 publications thorough the screening process.

The collection of 19 final publications are presented according to the research objectives intended namely RO 1; to explore how AI enhance student's critical thinking and RO 2; identifying the benefits and limitation of AI in modern education. The table 2 below shows the compilation of 19 selected article from the online databases:

Table 2: 19 Selected Articles from the Database

Title of Publication	Year
How Generative AI Influences Students' Self-Regulated Learning and Critical Thinking Skills? A Systematic Review	2025
Empowering ChatGPT with guidance mechanism in blended learning: Effect of self-regulated learning, higher-order thinking skills, and knowledge construction	2024
Cognitive and sociocultural dynamics of self-regulated use of machine translation and generative AI tools in academic EFL writing	2024
A human-centered learning and teaching framework using generative artificial intelligence for self-regulated learning development through domain knowledge learning in K-12 settings	2024
Do you have AI dependency? The roles of academic self-efficacy, academic stress, and performance expectations on problematic AI usage behavior	2024
Exploring the influence of student interaction with ChatGPT on critical thinking, problem solving, and creativity	2024
The influence of AI text generators on critical thinking skills in UK business schools	2024
Evaluating AI's impact on self-regulated language learning: A systematic review	2024
ChatGPT effects on cognitive skills of undergraduate students: Receiving instant responses from AI-based conversational large language models (LLMs)	2024
Three-wave cross-lagged model on the correlations between critical thinking skills, self-directed learning competency, and AI-assisted writing	2024
Collaborative working and critical thinking: Adoption of generative artificial intelligence tools in higher education	2024

Exploring the relationship between critical thinking, attitude, and anxiety in shaping the adoption of artificial intelligence in translation among Saudi translators	2024
Critical thinking in the AI era: An exploration of EFL students' perceptions, benefits, and limitations	2024
Enhancing English as a Foreign Language (EFL) learners' writing with ChatGPT: A university-level course design	2024
Examining relationships between technology and critical thinking: A study of South Korean EFL learners	2024
ChatGPT and its impact on research supervision: Insights from Australian postgraduate research students	2023
Enhancing STEM learning with ChatGPT and Bing Chat as objects to think with a case study	2023
ChatGPT, a brand-new tool to strengthen timeless competencies	2023
The concept of hybrid human-AI regulation: Exemplifying how to support young learners' self-regulated learning	2022

Result

RO 1: How Artificial Intelligence (AI) Enhance Student's Critical Thinking

According to a growing body of research, students' critical thinking skills may be significantly improved by AI-powered tools ranging from metacognitive prompts to generative chatbots and intelligent tutoring that create interactive, customized, and reflective learning experiences. ChatGPT, one of the AI-based tools help students to challenge their own thinking process, address visible weakness on their research and enhancing their capacity to think critically (Dai, Y et al.,2023). The tool also offers an application of real-life scenarios from a sampling method in which assist the students to develop their critical thinking skills (Essel, H.B et al.,2024). Leveraging the tool for in-class task has successfully improved student's critical thinking as it helps in developing deeper understanding and plays as an additional support for students who struggle to improve their skills (Essel, H.B et al.,2024). In line with this, the use of AI-based tool develops a better comprehension in handling an intricate task as a result of being prompted to evaluate the AI's inputs and outputs critically (Tseng, Y. C., & Lin, Y. H.,2024). Students that succeeded in developing a balanced approach of AI and upholding their creativity by the use of technology hence fulfilling the modern era's essential skill. Schenck, A. (2024) emphasis that students who viewed critical thinking as a means to see things from a different ways to approach a solution has a clear understanding on how technology could be used for future success.

A positive mindset toward technology may improve one's capacity to assess and evaluate information critically (Mahdi, H. S., & Sahari, Y. M.,2024). Hence, encouraging students to imply a positive view on AI-based tools and technology would initiate a robust development of critical thinking skills. Based on the study by Sardi, J, et al., (2025), 62.5% of studies shows that generative AI improve critical thinking by providing relevant reflective feedback, collaborative learning and analytical skills and problem solving. Another study conducts by Ruiz-Rojas, L. I. et al., (2024) shows that 64% of the respondents agree that generative AI-based tools significantly improve their ability to think critically. There is a fascinating links between a symbiotic connection of improvements in critical thinking and ChatGPT that may synergistically boost overall learning abilities (Qawqzeh, Y. 2024).

Another AI-based tool called GCLA has a different characteristic that ChatGPT but still has the same proposed as the assisted learning aid. The GCLA encourages students to offer their own ideas rather than providing answers directly. It then provides guidance that foster critical

thinking and prompting students to provide their own reasoning to reach a correct conclusion (Lee, H. Y et al.,2024). By giving students access to a variety of materials and viewpoints, generative AI technologies can enhance their capacity for critical thinking, analysis and evaluation of knowledge (Ruiz-Rojas, L. I. et al.,2024). It will encourage them to explore any alternative ideas thus leading to a deeper thinking. Students' critical thinking abilities may be improved by using ChatGPT to analyses complicated scenarios, comprehend difficult concepts, generate new ideas, expose them to fresh viewpoints, and validate input and output information (Essien, A et al.,2024). These findings collectively shows that the potential of AI-based tools in modern education could change the productivity of the learning's environment.

RQ2: What is Artificial Intelligence (AI) benefits and limitation in modern education

It is undeniable that AI-based tools have been used widely in modern education nowadays. The integration of AI has brought multiple opportunities, shaping a different way on how students learn, and educators teach in line with the digital age. Multiple studies outline the benefit of implementing AI-based tools in studies hence the learning environment become more conducive. AI-based tools are tailored to enhance learning outcomes for students while also teaching them to self-regulated through an assessment-based approach and computer-assisted assessment (Chang, W. L., & Sun, J. C. Y.,2024). Hence, encouraging students to actively engage an improve their learning. ALTs, another medium for AI that plays as the assisted learning aid can increase accuracy by overcoming student's poor capacity to appropriately manage alignment between their knowledge and difficulties (Molenaar, I.,2022). Not only influencing the learning environment, multiple AI-based tools also offer an AI-assisted writing such as ChatGPT, Grammarly and Quillbot to help in improving writing and assist the language learners (Shen, X., & Teng, M. F.,2024).

Students may develop their creative, critical thinking, and problem-solving abilities in a more approachable and interesting learning environment by using GenAlbots which include ChatGPT and Bing chat (Vasconcelos, M. A. R., & Santos, R. P. D.,2023). It is also found that using an AI chatbot can improve student's communication skills as it has the ability to enhance human-computer interaction (Kong, S. C., & Yang, Y.,2024). AI creates efficiency by offering quicker and more suitable answers to tasks (Sardi, J et al.,2025). Utilizing artificial intelligence (AI) can improve the caliber of student's work, not just beyond a simple error correction but also as a tool to help them strive for precision and eloquence (Wang, Y.,2024).

However, despite these advantages, the implementation of AI in education settings still cannot avoid the limitation. According to Shen, X., & Teng, M. F., (2024), due to the inaccuracy of AI-based tools' responses, students was somehow filled with confusion and anxiety due to the overreliance on AI-assisted tools without generating their own views, It has been projected that an excessive dependence on AI technology may harm individuals by impairing their capacity for critical thinking and problem-solving (Zhang, S et al.,2024). Using the personalization offers by the AI-based tools may cause students to become too dependents and take a passive approach to learning (Kong, S. C., & Yang, Y.,2024). Potential disadvantages of AI include its limited capacity for adaptation, the possibility of echo chambers, unreliability, and its incapacity to understand nuances which may present the possibility of bias and errors (Darwin et al.,2024). If students rely too much on ChatGPT for answers without really engaging with the material, it might provide inaccurate information that appears to be accurate and relevant, which can result in a lack of critical thinking (Michalon, B., & Camacho-Zuñiga, C.,2023). AI occasionally misunderstands context and casting doubt on its accuracy so students may receive illogical replies that can skew perspectives and potentially shaping their belief and attitude (Essien, A et al.,2024).While there were many limitations of AI reliance, according to Zhang, S. et al., (2024) the top five were diminished creativity, greater laziness, the spread of false information, and a decline in critical and independent thinking.

Table 3: Summary of Benefits and Limitations of AI in Education

Benefit	Limitation
Enhances critical thinking and problem-solving (Dai et al., 2023; Essel et al., 2024)	Risk of overreliance and reduced self-regulation (Zhang et al., 2024)
Supports personalized and adaptive learning (Chen et al., 2020; Celik et al., 2024)	Possible bias, misinformation, and ethical issues (Darwin et al., 2024; Essien et al., 2024)
Improves communication and writing skills (Tseng & Lin, 2024)	Anxiety and confusion from inaccurate AI responses (Shen & Teng, 2024)
Encourages collaborative and reflective learning (Ruiz-Rojas et al., 2024)	Passive learning and diminished creativity (Kong & Yang, 2024)

Discussion

This review highlights how critical thinking may enhance by the use of AI-based tools. Studies shows that Individuals who have a good attitude towards AI are more inclined to be critical thinkers, as indicated by the strong positive correlation between critical thinking and attitude. This would then imply that having a good attitude towards technology is more than likely to promote one's capacity for critical evaluation and appraisal of information. Therefore, promoting a good impression of AI can help towards developing good critical thinking skills. Those tools also acted as an assistance to guide students in obtaining answer from a different viewpoint. However, there are lack of studies that cover from the educator's perspectives regarding the validity of critical thinking's enhancement from AI-based tools so it solely based on the student's experience, perhaps future research might consider exploring from the educator's point of view so that the future findings may obtain an adequate and reliable data.

In terms of the benefits gains from artificial intelligence (AI), the review shows that AI-based tools help in writing, communication and language learning which are basically the basic component in education. The benefits vary from generating ideas, verifying grammatical accuracy, exploring alternative viewpoints, and validating arguments. However, a wider field of study might be suggested for future studies as it can enable collaboration and innovation from between the study's field.

Finally, the review also highlighting the limitation of artificial intelligence (AI) in educational settings. Most studies mentioned the overreliance and over-dependency of AI may limits the student's ability to perform productively, resulting in possible confusion and anxiety. Furthermore, potential bias and misinformation may misdirect the student's perspective thus eliminating the credibility of the said information. However, this ethical concern is not widely discussed, and a long-term implication of AI consumption are not explored. Future studies may grab this idea to produce a comprehensive study that may become the basis of artificial intelligence's policy in future education settings.

Conclusion

The central aims of this research project are to explore how AI can enhance student's critical thinking skills and identifying their benefits and drawback in this modern education. As mentioned before, education is going through a revolution where the adaptation of generative AI and AI literacy has empower students to change their learning method. Because the best tools that could assist students to think critically were those that provide contextual feedback and recommend relevant information that include multiple option from variety of viewpoint . It is beyond doubt that artificial intelligence (AI) bring impacts on critical thinking while introducing another layer of complexity and opportunity to educational technology. Educational technology which focuses on engineering education that enables critical thinking can provide a whole new standard for engagement while artificial intelligence (AI) is making it possible to promote a

more profound way to engage with concepts and learning materials rather than relying on basic features such as "question-answer". To grasp these benefits, we need policies that can act as support mechanism for reasonable and ethical use of technology especially the generative AI. Just like other technological advancement in education, artificial intelligence (AI) has the potential but its impact is determined by how we use and manage it. As AI evolves and grows in capability, we must have policymakers prepped to be ahead of the game in assessing the ethical and effective uses of AI, with ongoing fundamental training across higher education platforms.

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