Research Article

Can critical thinking and AI work together? Observations of science, Mathematics, and language instructors

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ABSTRACT

AI tools, such as intelligent tutoring systems, chatbots, and adaptive learning platforms, allow instructors to design teaching strategies based on individual student needs, learning styles, and progress. This exploratory study discussed the implications of AI use in classrooms for student's critical thinking. Science, mathematics, and language instructors (n=40) were purposively sampled to be interviewed in the study. Narrative data was analyzed for recurring themes through reflexive thematic analysis. Findings indicated that AI has an alternate purpose in developing and possibly obstructing students' critical thinking skills. AI tools like chatbots and personalized learning systems can enhance critical thinking by promoting cognitive flexibility, reflective thinking, and systematic analysis. Teachers use AI to encourage students to analyze AI-generated results and compare them to theoretical frameworks, developing deeper engagement with content across subjects like science, mathematics, and language. However, the study also observed that over-reliance on AI can lead to superficial understanding and uncritical acceptance of information. Students sometimes bypass the cognitive work necessary for critical thinking, treating AI as a shortcut rather than a tool for deeper learning. As such, while AI can significantly enhance learning when used appropriately, instructors must guide its use carefully to avoid negative impacts on critical thinking.

Keywords: artificial intelligence; critical thinking; learning; technology

1. Introduction

Critical thinking is essential for assessing information, solving problems, and making well-informed decisions in both academic and practical contexts[1,2]. The advent of Artificial Intelligence (AI) technologies has introduced a transformative element to this discourse. AI holds the promise of reshaping educational environments by customizing learning experiences and delivering real-time assessments, among other advantages[3,4].

AI is gaining recognition as a powerful tool for fostering critical thinking, especially in educational settings. However, its adoption is not without challenges, such as ethical concerns regarding data privacy and the risk of deepening educational inequalities[5]. Students' views on AI in education differ significantly,

ranging from feelings of empowerment to uncertainty[6].

The rising popularity of AI chat models among students can be attributed to their ease of access and convenience. These models are designed to generate responses tailored to specific prompts across various fields and disciplines, enabling students to use them for academic support[7]. While some scholars[8,9] advocate for the benefits of AI tools such as automated essay scoring and language learning applications in enhancing problem-solving and analytical skills, others[10,11] express concerns about AI algorithms perpetuating existing biases or impeding the development of independent thinking.

The integration of AI into education presents new opportunities for learners to leverage these chat models in assisting with academic tasks. As educational resources become increasingly accessible to students, it is essential that learning environments foster a collaborative atmosphere where both teachers and learners actively engage in the pursuit of knowledge[12]. The application of AI in education must be managed judiciously to ensure it supports rather than undermines critical thinking. Excessive reliance on AI for problem-solving or content creation could result in a passive learning experience, countering the objective of fostering active, critical thinkers. Thus, the design and deployment of AI tools are crucial. They should be developed to promote not just memorization or superficial understanding but to encourage inquiry, debate, and critical assessment[13].

AI tools, such as the chatbots analyzed by Hapsari and Wu[14], can offer diverse and intricate linguistic content, simulate real-life scenarios for critical examination, and provide personalized feedback, all of which are vital for nurturing profound comprehension and practical language application. Research by Slavin, Cheung and Zhuang[15] provides a valuable perspective by suggesting that critical thinking fundamentally involves challenging established norms and accepted knowledge. This perspective is reinforced by Alsaleh[16], who investigates pedagogical methods to foster questioning skills in students, asserting that questioning established norms is a core aspect of critical thinking.

This research aimed to evaluate the influence of AI tools on critical thinking development among instructors, particularly those teaching mathematics, science, and language. It investigated how these instructors incorporated AI into their instructional methods, aiming to pinpoint strategies that effectively leveraged AI to promote critical thinking. Additionally, the study provided insights into the design and integration of AI tools that supported instructional objectives, while also considering ethical concerns and challenges, ultimately contributing to more effective and equitable teaching practices.

2. Literature review

AI has emerged as a pivotal tool in the educational sector, contributing significantly to the processing, analysis, and dissemination of information across various disciplines. Zhang and Lu[17] highlighted that AI functions as a knowledge project, capable of absorbing and categorizing vast amounts of data. By organizing this data and expressing results based on user commands, AI enhances the efficiency and effectiveness of information management. Crompton and Burke[18] revealed that 72% of AI users within academic institutions are students. These students utilize AI to access learning materials, complete assessments, and conduct self-testing activities, showing that AI is becoming an integral component of student learning strategies.

In the Philippine context, the adoption of AI in education is still relatively new, and there are limited regulations and guidelines governing its appropriate and ethical use in academic settings. Estrellado and Miranda[19] pointed out the significant potential AI holds to enhance the overall learning experience, but they also noted a substantial gap in the current understanding of how AI impacts education in the Philippines. There remains an urgent need to explore how AI can be used to augment both learning processes and

teaching methodologies to improve academic performance. Bancoro[20] emphasized the necessity of further research to examine the potential connection between AI use and educational outcomes, especially in terms of how it interacts with various educational indicators within the Philippine context.

Despite the positive impacts of AI in education, several challenges accompany its integration into learning environments. One of the primary concerns, as noted by Luan et al.[21], is the potential decline in the quality of interpersonal communication between students and their teachers. The use of AI in education may reduce the face-to-face interaction that is critical for fostering meaningful relationships and deep learning. In addition to this, Goralski and Tan[22] warned that AI could widen existing inequalities in education. Students who lack access to the necessary technology, especially those from financially disadvantaged backgrounds, may face significant challenges in utilizing AI-based resources, further exacerbating the digital divide.

Although AI has the potential to enhance the efficiency of learning and teaching, it cannot fully substitute the essential human judgment and intervention required in educational settings. Rane, Desai and Choudhary[23] expressed concerns about the quality of content generated by AI, such as text from ChatGPT, highlighting that it often lacks the depth and coherence characteristic of work produced by humans. This has sparked discussions about the legal status and intellectual property issues related to AI-generated content in educational environments. Additionally, ethical questions arise regarding the application of AI in academic settings, emphasizing the importance of using AI tools responsibly to uphold the integrity of human intellectual contributions.

AI is revolutionizing the education sector by enhancing instructional methods and improving students' learning capabilities. AI has the potential to adapt to individual learners' needs by assessing their progress, performance, and preferences. This allows AI systems to provide customized learning experiences, recommend additional resources, and offer constructive feedback based on each student's specific requirements[24]. For example, using Quizizz enabled teachers to develop their competence in language teaching as it gives them opportunity to integrate gamified learning, creating dynamic and approachable learning processes for students[25]. Government learning systems have been impacted by digital transformation. This is especially true for new millennial employees who are very tech-savvy, as online quiz apps like Kahoot! and Quizizz provide fun and interesting learning resources[26]. One of the fundamental duties of academic institutions is to bridge the gap between students and their curriculum by assigning tasks that foster engagement, as well as training instructors to maintain interactive and dynamic relationships with their students[27].

According to Duman and Akdemir[28], AI has the potential to significantly increase research skills by automating repetitive and time-consuming procedures like issue identification and literature reviews. These efficiencies allow researchers to focus more of their cognitive energies on more difficult activities, such as forming hypotheses and interpreting data, which are essential for developing higher-order cognitive abilities[13]. However, there is still debate over how to successfully and meaningfully integrate critical thinking and AI use in a coherent way, despite positive findings about the impact of integrating AI and critical thinking activities on student learning[29]. AI use in classroom encourages students to think critically and to consider the advantages, drawbacks, and implications of using AI[30,31]. However, some argue that the proliferation of AI use in classrooms could encourage students to be reliant to AI which hampers the development of their critical thinking skills[32]. This paper addressed this limitation discussing how AI use can be effective in education with instructors' control, emphasizing ethical use of AI within the classroom setting.

Polak, Schiavo and Zancanaro[33] contended that incorporating AI into educational practices is crucial for empowering both students and teachers by improving their skills and knowledge. However, Schwartz et al.[34] warned that AI systems could unintentionally reinforce biases found in their training data. If these models are developed using biased datasets, they may replicate those biases, resulting in inequitable or unjust outcomes in practical applications. This underscores the necessity of thoroughly examining the data utilized to train AI systems to avoid biased results and promote fairness within educational environments.

Instructors and administrators in the Philippines have come to see AI as a powerful tool that can enhance teaching practices, streamline administrative processes, and boost research productivity. According to Giray et al.[35], teachers serve as the primary facilitators of AI integration in classrooms, making them vital in promoting AI literacy among students. Casal-Otero et al.[36] further noted that instructors are tasked with equipping students with the necessary skills to utilize AI effectively in their academic endeavors. However, Sanusi et al.[37] highlighted that many teachers encounter significant obstacles to achieving AI literacy, primarily due to a lack of training in AI technologies and the heavy workloads they already manage. This situation complicates their ability to incorporate AI instruction into their educational practices.

The integration of AI into the classroom also requires substantial effort from instructors, particularly when considering the complexity of their existing roles. Lin and Van Brummelen[38] noted that teachers are expected to make significant adjustments to incorporate AI education into their lessons, adding to their already demanding workload. Despite these challenges, the use of AI in education offers vast potential to revolutionize teaching and learning, provided that sufficient support is given to educators and students alike to navigate the complexities of AI technology.

3. Methods

3.1. Research design

This paper was an exploratory study on how critical thinking interacts with AI use based on the perspectives of science, mathematics, and language teachers. Exploratory designs were preliminary studies in nature as they are expected to understand a less understood phenomenon[39], like the emergence of AI use in classrooms. This design is effective for analyzing participants' experiences without imposing preconceived notions[40]. In the field of social sciences, *exploration* adheres to systematic and structured methodologies that are intentionally designed to improve the identification of fundamental patterns, which helps in learning and recording of components related to social or psychological phenomena[41,42]. Exploration provides useful information into a phenomenon, and as such, it is often anticipated to aid in the development of hypotheses derived from its findings[43]. Given AI use in classrooms can be considered as an emergent phenomenon[44], it becomes interesting to explore its implications in essential learning aspects—like critical thinking.

3.2. Population and sampling

The participants of this study consisted of 40 science, mathematics, and language teachers from the Biliran Province, Philippines. A purposive sampling technique[45] was employed to select participants who have firsthand experience in integrating AI into their teaching practices. This method ensures that the study focuses on instructors who are directly involved in using AI in the classroom, allowing for a comprehensive exploration of their unique experiences. In selection, several key characteristics were identified to ensure the relevance and depth of the data collected. These characteristics include the participants' familiarity with AI technologies, their years of teaching experience, the subjects they teach, and the extent to which AI tools have been integrated into their instructional practices (at least a year).

3.3. Research instrument

Semi-structured interviews were the primary data collection tool used in this study. This instrument allowed for flexibility in the conversation, enabling the researcher to explore specific aspects of AI integration while also providing room for participants to express their unique perspectives. According to Chavez et al.[46], connecting ideas during exploratory research is necessary to understand participants' viewpoints. The interview questions were designed to cover topics such as AI integration methods, safeguards for responsible use, and the challenges and benefits experienced by the instructors. **Table 1** presents the summary of interview guide questions used during one-on-one interviews.

Table 1. Interview guide questions.

Objectives	Interview Questions
Determine the specific strategies instructors use to integrate AI into science, mathematics, and language lessons to foster critical thinking.	1. What are your strategies for using AI to integrate critical thinking into your students' learning? 2. How does AI serve as a tool for critical thinking in your instruction? 3. What are your controls or regulations in using AI to foster critical thinking in your lessons?
Explore the barriers and advantages instructors experience when incorporating AI into their teaching for critical thinking development.	1. What difficulties have you faced when trying to integrate AI into your teaching practices, particularly in fostering critical thinking among your students? 2. What benefits have you observed from using AI tools in your lessons in terms of promoting critical thinking? 3. How do you manage AI in promoting critical thinking while ensuring that it is not misused by students?

3.4. Data gathering procedure

The data were gathered through one-on-one interviews with the participants, a method that facilitated an in-depth exploration of their experiences and viewpoints. One-on-one interviews are effective in eliciting detailed and personal insights from participants[47].

Each interview was conducted in a private and comfortable setting, ensuring that participants felt secure in sharing their experiences. The interviews were audio-recorded with the participants' consent and later transcribed for analysis. Classroom observations were conducted either before or after the interviews, depending on the instructors' schedules. This allowed the researcher to directly observe the integration of AI into the teaching process, further validating the data collected during the interviews.

3.5. Data analysis

A reflexive thematic analysis[48] was employed to analyze the data, with the researcher carefully identifying themes from the interviews and observations. This method was selected due to its balance of flexibility and structure in interpreting qualitative data. The transcribed interviews and observation notes were coded, leading to the development of themes based on recurring patterns. As Chavez et al.[47] noted, exploratory research allows researchers to link ideas and establish a groundwork for more in-depth analysis without enforcing strict assumptions. This approach was crucial for understanding the varied and complex ways instructors incorporate AI into their teaching methods. **Figure 1** presents the *iterative* six phases of reflexive thematic analysis[48].
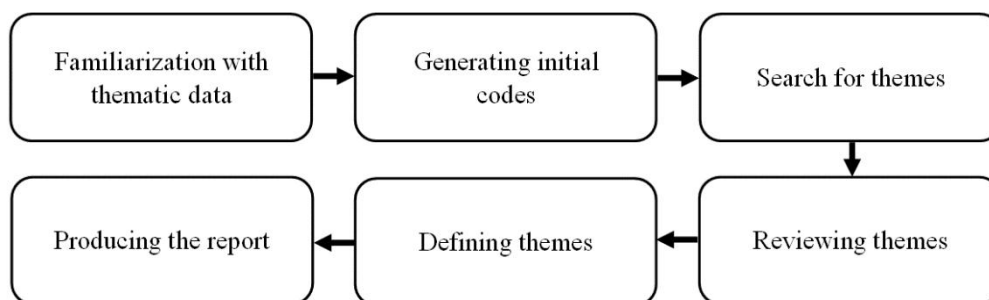
Figure 1. Reflexive thematic analysis guide.

4. Results

Objective 1. Determine the specific strategies instructors use to integrate AI into science, mathematics, and language lessons to foster critical thinking.

Theme 1: Direct Application

Direct application captures how instructors use AI tools as a way to directly engage students in critical thinking exercises. This theme emphasizes strategies where AI is not only a supplementary tool but also a catalyst for deeper cognitive engagement.

One common strategy is guiding students to *examine AI-generated outputs critically*. Rather than accepting AI-generated answers at face value, instructors emphasized the importance of understanding the process behind these results. This approach promotes deeper cognitive engagement, requiring students to *evaluate the reasoning* behind AI responses and compare them with their own solutions.

> "I always challenge them to look beyond the answers provided by AI and critically examine the process behind the results."

> "By using AI-driven platforms, students are encouraged to engage in meaningful discussions about their findings, thus improving their communication skills."

Instructors encourage students to compare their own perspectives with AI's insights, thereby helping them develop the ability to assess *differences in reasoning* between human and machine-generated answers. This technique sharpens students' critical evaluation skills by challenging them to reflect on the limitations and strengths of both their understanding and the AI's output.

Instructors also incorporate *AI-driven discussions* as a means to improve both critical thinking and communication skills. Using AI platforms, students engage in *dialogue about their findings*, which encourages them to think more critically about the arguments presented and to articulate their viewpoints more effectively. This method emphasizes a more interactive, reflective learning process where students are *exposed to various perspectives*.

> "By comparing their thoughts with the AI's analysis, they learn to critically evaluate both their perspectives and the limitations of AI."

> "I ask them to compare the AI's solutions with their own and analyze which steps differed."

> "I emphasize the importance of verifying AI-generated information against reputable sources."

"This method encourages them to think critically about the arguments presented, consider different angles, and articulate their own viewpoints with supporting evidence."

"I have specific assignments where they are required to justify their answers both from AI outputs and traditional methods."

"I utilize AI to present various viewpoints, including historical and cultural contexts."

Moreover, *responsible AI usage* is evident in how instructors guide students to verify AI-generated information against reputable sources. This practice reinforces the importance of academic integrity and ensures that students develop discernment when using AI in their academic work.

"I provide clear guidelines on how students should use AI tools responsibly, emphasizing the importance of academic integrity."

In mathematics, instructors integrate traditional methods with AI by requiring students to complete *foundational tasks without AI* before integrating AI tools into more complex problem-solving activities. This ensures that students build a solid foundation of knowledge and skills before relying on AI, fostering a balanced approach to learning where *traditional methods and AI outputs* are critically examined and justified.

"First, students must complete certain foundational tasks—such as solving equations or plotting graphs—without AI assistance."

"To prevent the misuse of AI, I incorporate reflective assignments where students must explain their reasoning and how AI helped them arrive at a solution."

Theme 2: Reflection

This theme centers on how instructors integrate reflective practices alongside AI tools to deepen students' critical thinking and ensure thoughtful engagement with the technology. Reflection, as a strategy, encourages students to *consciously evaluate their thought processes* when using AI, ensuring that they don't rely on it as a shortcut but rather to enhance their learning.

A key component of this theme is the use of *reflective assignments*, where students are required to explain their reasoning and how AI contributed to their problem-solving process. This practice not only helps students internalize their learning but also encourages *self-awareness* in distinguishing between their ideas and AI suggestions. By having students engage in *reflective reporting*, they are prompted to articulate the impact of AI on their understanding, encouraging a deeper consideration of how AI influences their academic work.

"This reflective practice helps ensure that AI is being used as a tool to enhance critical thinking rather than as a shortcut."

"Regular check-ins during the learning process also allow me to monitor."

"To prevent the misuse of AI, I incorporate reflective assignments where students must explain their reasoning and how AI helped them arrive at a solution."

"I require students to write reflective reports after each AI-based activity, explaining their thought processes and how AI contributed to their understanding of the topic."

Instructors also incorporate *regular monitoring* through structured check-ins, allowing them to track how students are interacting with AI and ensuring that it is being used as an educational aid rather than a crutch. This oversight ensures that students remain engaged in *critical self-evaluation* throughout the learning process.

> "I implement a system of checks where students must present both their original ideas and any AI suggestions in their assignments."

In science education, instructors leverage AI tools to push students beyond passive observation and encourage deeper *critical reflection* on AI-generated outputs. Instead of allowing students to merely summarize what AI has done, instructors emphasize the importance of engaging in *critical analysis* of AI results. This means students are expected to *evaluate the reasoning* behind the AI's conclusions and *compare these outcomes* with established scientific theories or concepts discussed in class.

> "I emphasize that they must not simply describe what the AI did but critically analyze why it produced certain results and how those results align or conflict with scientific theories we've discussed."

Theme 3: Interactive Learning

This highlights the use of AI-driven tools to promote active student engagement and critical thinking through interactive platforms. Instructors employ AI-powered applications like *Kahoot* and *Quizizz*, which use game-like elements to *encourage participation* and foster a more dynamic learning environment. By integrating critical thinking exercises into these platforms, students are engaged in learning activities that require quick thinking and thoughtful decision-making, making the process both educational and enjoyable.

> "I strategically integrate critical thinking into students' learning by using AI tools such as Kahoot and Quizizz."

> "These platforms offer engaging, game-like quizzes that encourage active participation."

With AI, *simulations, games, and virtual labs* are used to allow students to experiment with various variables, prompting them to *analyze cause-and-effect relationships*. This hands-on approach encourages students to apply theoretical knowledge to practical scenarios, thus deepening their understanding and reinforcing critical thinking through experiential learning.

> "Tools like simulations, games, or virtual labs encourage students to experiment with different variables, which requires them to think critically about cause and effect."

Theme 4: Ethical Teaching

This revolves around how instructors emphasize the responsible and principled use of AI in educational settings. Central to this theme is the creation of *clear ethical guidelines* that define how students should engage with AI tools. Instructors establish boundaries and provide thorough instruction to ensure that AI is used to *complement students' work* rather than replace it, preventing potential issues such as plagiarism.

> "I ensure AI is used ethically by setting clear guidelines for its use in class. Before granting students access to AI tools, they receive thorough instruction on ethical considerations, such as avoiding plagiarism and using AI to complement their work rather than replace it."

To reinforce ethical engagement, instructors implement *structured assignments* where students are required to explain the *reasoning behind their use of AI*, rather than merely relying on AI outputs. This encourages students to *critically analyze* AI-generated results and reflect on how those results align with or challenge established scientific or academic concepts discussed in class.

> "In addition to ethical guidelines, I create scenarios where students must explain how they used AI to arrive at their solutions."

> "I believe to further prevent misuse, I implement structured assignments where students must explain their reasoning process after using AI."

> "I establish clear limitations and guidelines for when and how AI can be utilized."

Objective 2. Explore the barriers and advantages instructors experience when incorporating AI into their teaching for critical thinking development.

Theme 1: Downfall of Critical Thinking

This theme highlights concerns about the potential negative impact of AI on students' cognitive development. A key issue raised by instructors is the risk of *overreliance on AI*, where students may increasingly depend on AI tools to bypass challenging tasks that require deep thinking. This *overconsumption of AI* can result in a decline in students' ability to engage in independent problem-solving, as they may come to view AI as a *shortcut* for avoiding critical thinking and intellectual effort.

Instructors emphasize that such dependency on AI tools could undermine the development of essential *cognitive skills* like analysis, reasoning, and evaluation. When students frequently turn to AI for answers, there is a reduced need for them to engage in the *difficult cognitive work* that fosters intellectual growth. This growing reliance could, over time, weaken their capacity to think critically and independently, potentially leading to a broader decline in *creative and analytical thinking* skills within the academic environment.

> "Overconsumption or codependency to AI will be the downfall of critical thinking."

> "Many students tend to see AI as a shortcut to avoid the difficult cognitive work."

Theme 2: Unreliable Contents

This theme focuses on the risks associated with students accepting AI-generated information without skepticism. A significant concern is that many students may view *AI outputs as infallible*, taking them at face value and failing to question their validity. This tendency to rely on AI-generated results without critical engagement can lead to a misguided trust in the technology, which may not always provide accurate or reliable information.

Instructors point out that this uncritical acceptance can undermine students' ability to develop *critical thinking skills* necessary for evaluating sources and information. When students do not actively *question or analyze* AI outputs, they miss opportunities to engage deeply with the material, which is essential for cultivating a robust understanding of complex topics.

This overreliance on AI can contribute to a broader issue in education where students may struggle to discern *reliable content* from misinformation. The lack of critical engagement with AI-generated responses not only diminishes their learning experience but also poses challenges in developing the necessary skills to navigate the vast amounts of information available in today's digital landscape.

"Some students accept AI-generated results without questioning their validity."

"Some students take AI outputs at face value, believing they are infallible."

"Some students tend to rely on AI-generated responses without critically engaging with the material."

Theme 3: Exposure to Contents

This theme highlights the role of AI tools in broadening students' access to diverse information and perspectives. By utilizing AI, students are introduced to a *wider range of data and methods* that they may not have previously encountered, enriching their research experience. This increased exposure allows students to engage with multiple viewpoints and sources, prompting them to *evaluate the credibility* of the information and *compare different arguments* critically.

AI-generated articles often present various sides of an issue, which encourages students to *analyze diverse perspectives* and synthesize information from different sources. This interaction with complex content, presented in a more *accessible manner*, enables students to delve deeper into topics, fostering a greater understanding of the material.

"AI tools expose them to a wider range of data and methods that may not have been previously considered."

"When students conduct research on a scientific topic using AI, they encounter multiple viewpoints and sources… this prompts them to evaluate the credibility of the information and compare different arguments."

"Students can access various AI-generated articles that present different sides of an argument."

"AI tools present complex information in an accessible way, allowing students to explore topics more deeply."

Furthermore, the use of AI tools acts as a catalyst for enhanced engagement, encouraging students to adopt a *more questioning mindset*. This shift towards critical inquiry is essential for developing analytical skills, as students learn to navigate and interpret a wealth of information effectively.

"This exposure encourages them to engage with material critically, analyze various viewpoints, and synthesize information."

"AI acts as a catalyst for enhanced engagement and encourages students to adopt a more questioning mindset."

Theme 4: Feedback Learning

This theme emphasizes the significant advantages of using AI tools in educational settings, particularly in providing students with instant feedback on their work. AI offers *immediate responses*, enabling students to receive *step-by-step solutions* that facilitate a deeper understanding of the material. This rapid feedback loop allows students to quickly *identify mistakes* and make necessary adjustments to their thinking.

"AI offers instant feedback… students can get immediate responses from AI tools, which provide step-by-step solutions."

"The immediate feedback provided by AI allows students to quickly identify mistakes and adjust their thinking."

The real-time nature of AI feedback encourages students to engage in *immediate reflection* on their work, which is crucial for refining their critical thinking approaches. By receiving timely insights into their performance, students can *refine their critical thinking processes*, allowing them to better understand complex concepts and improve their overall academic skills.

> "AI provides real-time feedback, allowing students to immediately reflect on their work and refine their critical thinking approaches."

> "Students can get immediate feedback and refine their critical thinking processes."

This quick response mechanism helps students reflect on their errors, promoting a mindset focused on *continuous improvement* and learning. The ability to quickly assess their understanding fosters a proactive approach to learning, where students feel empowered to take charge of their educational journey.

> "This quick response from AI tools helps them reflect on their mistakes and improve their thinking process."

Theme 5: Interactive User Interface

This theme highlights the role of AI tools in creating a more engaging and interactive learning environment for students. These tools enhance lessons by fostering *active participation*, encouraging students to think more critically about the material presented. The *interactive nature of AI* not only captivates student attention but also stimulates lively discussions in class, where students can *defend their ideas* and *challenge each other's perspectives*.

> "AI tools make lessons more interactive and engaging, which encourages students to think more critically."

> "The interactive nature of AI often leads to lively discussions in class, enhancing their critical thinking skills as they defend their ideas and challenge each other's perspectives."

AI tools facilitate *personalized learning experiences*, allowing students to explore subjects at their own pace, which can lead to deeper understanding and retention of information. This level of engagement promotes critical thinking as students are encouraged to actively *analyze material* rather than passively receive information.

> "AI tools facilitate personalized learning experiences, allowing students to explore subjects at their own pace."

> "AI engages students in a way that promotes active participation and helps them critically analyze material."

5. Discussion

Robert Ennis, a distinguished specialist in critical thinking research, characterizes critical thinking as sophisticated and rational deliberation occurring during the decision-making process regarding beliefs or actions[49]. Despite the considerable variation in definitions among experts and academics, they invariably embrace analyzing data, judging and evaluating, making choices, and drawing inferences through inductive-deductive reasoning[50,51]. This paper observed consistency in the definitions of critical thinking in relation to AI use in classrooms. The definitions of critical thinking in the context of AI use remain consistent, with an emphasis on *evaluation*, *analysis*, *reflection*, *problem-solving*, and *creativity*, all of which are integral to the

learning process—something that was also common across science, mathematics, and language education. In general, critical thinking pertains to the analysis and evaluation of the advantages and disadvantages, veracity, and fallacy of a certain entity or phenomena; it involves the examination, scrutiny, and discourse of cognitive objects to generate clear, relevant, and precise insights[52,53].

AI is progressively regarded as an effective tool to enhance critical thinking abilities, particularly in educational environments[13]. Research[14,54] indicates that AI technologies, such as chatbots, function as self-regulated learning platforms to enhance speaking skill and mitigate emotional hurdles, including fear. The role of AI in skill and emotional development is further emphasized in the research of Xiao and Zhi[55], highlighting the distinct skills of ChatGPT as a personalized learning support. Recurring pattern was observed in this paper about the context of self-regulated learning among students. For example, one teacher said that students *"...must not simply describe what the AI did but critically analyze why it produced certain results and how those results align or conflict with scientific theories."* At emotional level, these technologies encourage *reflective thinking* by prompting students to engage with AI responses on a deeper level, analyzing both their own understanding and the AI's outputs. Bahufite, Kasonde-Ng'andu and Akakandelwa[56] assert that characteristics such as trust and confidence in themselves can be enhanced by AI-assisted learning, influencing not only language acquisition but also the development of critical thinking skills. This paper observed why: as AI tools have been described as promoting *cognitive flexibility*, where students adapt their thinking to different viewpoints presented by AI, enhancing their ability to *synthesize information* from various sources, making them fluent in the task itself.

In a qualitative study of Darwin et al.[13] among Indonesian master's students, it underscored the need of methodical frameworks for analyzing material, revealing the necessity of systematic methodology and logical examination in both statistical and literary analysis. Research by Shaw et al.[57] on critical thinking in higher education emphasizes the necessity for systematic approaches to problem-solving, while Mohseni et al.[58] underline the significance of these abilities in the proper interpretation of statistical data. Similar perspectives the teachers hold in using AI in their classrooms. For them, AI is seen as a tool that requires students to engage in *systematic reasoning* to dissect AI-generated results and compare them to theoretical frameworks or empirical data discussed in class. Teachers consistently emphasize the importance of *analytical thinking*, ensuring that students use AI not just to obtain answers but to *critically examine* the process that leads to these results. As one teacher said about language learning in AI, she *"...[requires] students to write reflective reports after each AI-based activity, explaining their thought processes and how AI contributed to their understanding of the topic."* In mathematics, *"students must explain their reasoning and how AI helped them arrive at a solution." Reflective practice* is often incorporated, where students are encouraged to think critically about how AI aids their learning while recognizing the *limitations* and *ethical considerations* of relying too heavily on such tools. These studies and classroom practices together underscore the role of *systematic analysis*, *critical evaluation*, and *logical methodology* in cultivating students' critical thinking, particularly when AI tools are integrated into educational environments.

Critical thinking is a continuous process that requires well defined cognitive goals to address certain problems or reach conclusions[50]. This notion corresponds with the meta-analysis by Abrami et al.[59], which offers empirical evidence for the multi-dimensionality of critical thinking competencies, and the study by Bezanilla et al.[60], which emphasizes the cultivation of these skills through various educational approaches. the integration of AI tools serves as a catalyst for *interactive learning* and *feedback learning*. AI's *immediate feedback* provides students with real-time opportunities to *reflect on their mistakes* and refine their *thinking processes*, reinforcing the iterative nature of critical thinking. Critical thinking is essentially a *multi-dimensional* skill set, wherein students must engage with content in multiple ways—*comparing, analyzing,*

reflecting, and *questioning*—to truly master these competencies. In Darwin et al.[13] study, it emphasized the importance of interrogating and contesting established standards, promoting skepticism and stringent evaluation as proactive measures to enhance understanding. Slavin, Cheung and Zhuang[15] assert that critical thinking involves questioning accepted norms and conventional wisdom, indicating that the capacity to contest existing concepts is vital for profound comprehension and knowledge progression.

There were instances where AI use can be detrimental to critical thinking skills of students. This concern is not new, as various discussions have raised alarms about the potential drawbacks of relying on AI. For example, using AI in research, these algorithms frequently fail to fit with specific criteria for selecting scholarly papers, potentially constraining prospects for comprehensive critical study[61,62]. Ryan[63] insists the necessity for skepticism regarding the results produced by AI analytics tools, particularly given that erroneous initial configurations may result in misleading or inaccurate outcomes. This paper also observed that AI use, particularly when over-relied upon, could lead to the *downfall of critical thinking* among students. Many instructors, especially in science and language, noted that some students tend to treat AI as a shortcut, avoiding the *difficult cognitive work* required for deeper analysis. This aligns with previous studies that highlight the dangers of students accepting AI-generated content at face value, as seen in the *overconsumption* of AI or the *uncritical acceptance of unreliable contents*. Students often overlook the importance of *engaging critically* with the material, leading to a superficial understanding of complex topics.

6. Conclusion

This study highlighted the double-edge role AI played in developing and sometimes hindering critical thinking among students. On the one hand, AI served as an effective tool to enhance critical thinking skills through interactive learning and feedback learning, offering immediate responses that facilitated reflection and problem-solving. When properly integrated, AI promoted cognitive flexibility, enabling students to engage deeply with content by analyzing and comparing different perspectives. Teachers were crucial in guiding students to move beyond AI-generated results and develop a more thorough understanding of complex topics by encouraging reflective practices and systematic reasoning. On the other hand, over-reliance on AI resulted in uncritical acceptance of unreliable content, where students neglected the need for deeper cognitive engagement. The study stressed that while AI could be a powerful educational tool, its usage had to be carefully moderated to prevent the downfall of critical thinking.

This exploratory analysis is significant for instructors, policymakers, and technology developers. First, instructors must actively design learning environments where AI is used as a complement, not a substitute, for critical analysis and problem-solving. Teachers should continue to emphasize reflective practice and require students to engage in analytical thinking to ensure that AI is utilized in a way that enhances, rather than detracts from, critical thinking development. For policymakers, these findings suggest a need for frameworks that guide the ethical and pedagogically sound integration of AI into educational curricula. Technology developers should prioritize creating AI tools that promote active engagement, encourage cognitive flexibility, and present information that challenges students to think critically rather than passively accept generated outputs.

Several limitations are present in this study. First, the scope was confined to teachers' perceptions of AI use in educational settings, which may not fully capture the broader impact of AI on critical thinking across different disciplines. Second, the study primarily focused on qualitative data, which limits the ability to quantify the precise extent of AI's influence on critical thinking skills. Furthermore, the sample size may not be representative of the wider educational landscape, potentially restricting the generalizability of the

findings. Hence, future research could explore longitudinal impacts of AI use on critical thinking and include more diverse educational settings and technological applications to better understand its broader implications.

Conflict of interest

The authors declare no conflict of interest.

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