

AI as a catalyst for metacognition: new frontiers in critical literacy for the digital age

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ABSTRACT

This mixed-methods study investigates the role of artificial intelligence (AI) as a catalyst for metacognition and its impact on college students' conceptions of critical literacy in the digital age. Sixty students from diverse academic backgrounds at Institut Studi Islam Muhammadiyah Pacitan, Indonesia, participated in an AI-based learning activity designed to facilitate literary analysis. Using pre- and post-intervention surveys and semi-structured interviews, we examined changes in students' metacognitive awareness and perceptions of AI's role in developing critical literacy skills. Results reveal significant shifts in students' metacognitive processes and understanding of critical literacy following AI interaction. Quantitative data show increased recognition of AI's potential to enhance personalized learning (mean score increase from 3.6 to 4.12) and critical thinking skills (mean score increase from 3.05 to 3.85). Qualitative findings indicate that AI interaction triggered deeper metacognitive reflection, with students reporting enhanced awareness of their thinking processes during literary analysis. Moreover, students' conceptions of critical literacy expanded to encompass AI literacy, recognizing the importance of effectively using and evaluating AI tools in the digital landscape. While privacy concerns decreased post-intervention, students maintained a nuanced awareness of potential ethical issues in AI-augmented learning environments. This study contributes to our understanding of how AI can serve as a powerful tool for fostering metacognition and redefining critical literacy in the digital age. It highlights the need for intentional integration of AI in educational settings to maximize its potential as a catalyst for deeper, more reflective learning experiences. The findings have significant implications for curriculum design, teacher training, and the development of AI-enhanced educational tools that promote metacognitive growth and critical literacy skills essential for navigating an increasingly AI-infused world.

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1. Introduction

Artificial intelligence (AI) is rapidly transforming education through technologies such as machine learning, natural language processing, and data analytics (Smith 2021). While much attention has been paid to AI's potential for personalized learning and adaptive instruction, a crucial area of investigation is emerging: AI's role in catalyzing metacognition and reshaping critical literacy for the digital age.

Specific applications of AI, such as intelligent tutoring systems, text analysis tools, and conversational agents, have the potential to not only enhance literacy instruction but also to fundamentally alter how students think about their own thinking processes (Jones 2019). This intersection of AI and metacognition opens new frontiers in critical literacy, challenging traditional conceptions of what it means to be literate in an AI-infused world.

As Kumar and Vig (2019) argue, studying student interactions with AI provides "an invaluable window" into how humans engage with these complex technologies. This engagement goes beyond mere tool use; it potentially triggers deep reflective processes that can enhance metacognitive skills. However, integrating AI also poses challenges around ethics, bias, and privacy that demand thoughtful consideration (Nagle 2019, Bu 2022), particularly in how these issues impact students' critical thinking development.

Prior studies have explored student perspectives on educational technology generally, with findings suggesting both excitement for personalized learning and concerns about privacy and interpersonal connections (Williams 2016, Henderson et al. 2017). More recent investigations into student perceptions of AI technologies specifically have revealed a nuanced landscape of optimism tempered by wariness of over-reliance on algorithmic recommendations (Essuman 2019, Ng 2022).

However, limited work has deeply explored how engagement with AI systems explicitly designed for advancing literacy might trigger metacognitive processes and reshape students' understanding of critical thinking in a digital context. This study aims to address that gap by examining how college students' metacognitive awareness and conceptions of critical literacy evolve through hands-on experience with an AI-powered reading activity.

Specifically, this research investigates:

1) How do students conceptualize the role of AI in developing their metacognitive skills and critical reading capabilities?

2) How does direct engagement with an AI learning activity influence students' awareness of their own thinking processes and their understanding of critical literacy in the digital age?

To explore these questions, 60 college students participated in an interactive classroom session using an AI chatbot designed to generate critical thinking prompts for short story analysis. This experience served as a catalyst for metacognitive reflection, challenging students to reconsider their approaches to critical reading and thinking in an AI-augmented learning environment.

Mixed-methods data analysis revealed key themes in how students' metacognitive awareness and perceptions of critical literacy shifted after this firsthand experience. While openness to AI as a learning tool increased, students also demonstrated a more nuanced understanding of the metacognitive demands of engaging critically with AI-generated content.

Results highlight the potential of AI as a powerful trigger for metacognitive growth and the expansion of critical literacy skills. They also underscore the need for educational approaches that deliberately harness AI to foster deeper, more reflective learning experiences. This study aims to inform policies and practices that fulfill AI's potential to augment human intelligence equitably, emphasizing the development of metacognitive skills and critical literacy that will serve students well in an increasingly AI-mediated world.

The insights gained here emphasize the need for continual open dialogue and centering of student voice in developing AI-enhanced learning environments. By understanding how AI acts as a catalyst for metacognition, we can better prepare students to navigate the complex landscape of information and technology in the digital age, fostering a new dimension of critical literacy that encompasses both human and artificial intelligence.

2. Method

This study employs a mixed-methods approach, combining quantitative surveys and qualitative semi-structured interviews, to investigate how AI acts as a catalyst for metacognition and reshapes college students' understanding of critical literacy in the digital age. This methodology allows for rich, multi-faceted insights into the complex interplay between AI engagement, metacognitive processes, and evolving conceptions of critical literacy.

2.1. Participants

The study involves 60 college students purposefully selected from Institut Studi Islam Muhammadiyah Pacitan, representing a variety of disciplines and levels of prior AI experience. This

diverse sample ensures a range of perspectives on AI's role in education and its impact on thinking processes.

2.2. Data Collection

- Pre-intervention metacognitive awareness and AI perception survey
Participants first complete a pre-intervention survey comprising 20 items:
 1. 10 items from the Metacognitive Awareness Inventory (MAI) (Schraw & Dennison, 1994), focusing on knowledge of cognition and regulation of cognition.
 2. 10 items assessing attitudes towards AI in education, using a 5-point Likert scale (1=strongly disagree, 5=strongly agree).The AI-related items cover:
 1. Perceived potential of AI to enhance metacognitive skills
 2. Role of AI in developing critical literacy for the digital age
 3. Anticipated impact of AI on students' thinking processes
 4. Ethical considerations in AI-augmented learning environments
- AI-based learning activity
Participants engage individually with a conversational AI chatbot designed for literary analysis. The chatbot, developed specifically for this study, is programmed to:
 1. Facilitate critical thinking about a short story through interactive dialogue
 2. Generate questions that prompt metacognitive reflection
 3. Provide adaptive recommendations based on the student's responses
 4. Explicitly draw attention to the student's thinking processesThis AI-based learning activity serves as a catalyst for metacognitive experiences, challenging students to reflect on their cognitive strategies and understanding of critical literacy in an AI-augmented context.
- Post-intervention survey and semi-structured interviews
Following the AI interaction, participants complete a post-intervention survey mirroring the pre-intervention instrument. This allows for quantitative assessment of changes in metacognitive awareness and perceptions of AI's role in critical literacy development. Subsequently, all participants engage in 30-minute semi-structured interviews. The interview protocol explores:
 1. Students' metacognitive experiences during the AI interaction
 2. Changes in their understanding of critical literacy in the digital age
 3. Perceptions of how AI influenced their thinking processes
 4. Reflections on the potential and limitations of AI in fostering metacognition and critical thinking

2.3. Data Analysis

Quantitative data from the pre- and post-intervention surveys will be analyzed using paired t-tests to assess changes in metacognitive awareness and AI perceptions. Effect sizes will be calculated to determine the magnitude of any observed changes.

Qualitative data from the interviews will be transcribed and analyzed using thematic coding techniques, as described by Gibson and Brown (2009). The analysis will focus on identifying recurring patterns and themes related to:

- Metacognitive triggering by AI interaction
 - Evolving conceptions of critical literacy
 - Perceived impact of AI on thinking processes
 - Ethical considerations in AI-augmented learning
- The word "data" is plural, not singular.

The mixed-methods approach allows for triangulation of data, providing a comprehensive understanding of how AI serves as a catalyst for metacognition and reshapes students' understanding of critical literacy in the digital age.

Throughout the research process, the study adheres to rigorous validity measures, confidentiality protections, and ethical guidelines to ensure the integrity and ethical conduct of the investigation.

3. Findings and Discussion

This study examined the metacognitive experiences and evolving perceptions of critical literacy among 60 college students as they engaged with an AI-based learning tool. Employing a mixed-methods approach, we collected data through pre- and post-intervention surveys and semi-structured interviews. Our primary aim was to investigate how interaction with AI serves as a catalyst for metacognitive processes and reshapes students' understanding of critical literacy in the digital age.

3.1. Pre-Intervention Survey

To establish a baseline understanding of students' metacognitive awareness and perceptions of AI in learning, we administered a pre-intervention survey. This instrument consisted of 15 items using 5-point Likert scales (1 = strongly disagree, 5 = strongly agree). The survey explored various dimensions, including:

- Students' awareness of their own thinking processes (metacognition)
- Perceptions of AI's potential to enhance critical thinking and literacy skills
- Understanding of critical literacy in the context of AI and digital technologies
- Ethical considerations surrounding AI in education

The following table presents the mean, standard deviation, and mode for each survey item. These statistics provide insight into the central tendency, variability, and most common responses among participants before their interaction with the AI-based learning tool.

Table 1. Learning statistics before interacting with AI-based learning tools

No.	Question	Mean	SD	Mode
1	AI tutors can provide personalized learning experiences similar to human teachers.	3.6	1.30	5
2	AI tools could enhance my critical reading and analysis abilities.	3.05	1.76	5
3	AI-based literacy training would likely be customized to my specific needs and abilities.	4.05	1.19	5
4	AI could provide literacy instruction to more students, especially in remote areas.	3.55	1.50	5
5	I am excited by the potential benefits of AI for enhancing student literacy.	3.65	1.78	5
6	With guidance from instructors, AI tutors could significantly enhance my learning.	3.25	1.69	3
7	I worry AI may breach the privacy of student data.	4.1	1.21	5
8	I worry AI may reproduce harmful biases in interpreting textual meaning.	3.35	1.81	5
9	AI-based writing tools may fail to grasp context, rhetorical style, and richer meanings.	3.65	1.50	5
10	AI writing assistants could perpetuate biases and style/tone conventions without wisdom.	3.80	1.62	5
11	I fear AI may be used coercively rather than empoweringly in education if not developed carefully.	4.25	1.21	5
12	Over-reliance on AI in education could hinder development of independent thinking.	3.75	1.64	5
13	I am skeptical AI can develop the advanced reasoning needed for true critical thinking.	4.05	1.50	5
14	AI lacks the emotional intelligence and wisdom of human teachers.	3.8	1.62	5
15	AI has inherent limitations compared to human cognition and understanding.	3.75	1.64	5

This pre-intervention data serves as a crucial reference point, allowing us to track shifts in metacognitive awareness and perceptions of AI's role in critical literacy development following the AI-based learning activity.

3.2. Post-Intervention Survey Results

Following the AI-based learning activity, we administered a post-intervention survey to assess changes in students' metacognitive awareness and perceptions of AI's role in developing critical literacy skills. This survey consisted of 15 items, mirroring the pre-intervention questionnaire, to allow for direct comparison and measurement of shifts in attitudes and awareness.

The post-intervention survey was complemented by semi-structured interviews with 12 randomly selected participants. These interviews provided deeper insights into students' metacognitive experiences during AI interaction and their evolving understanding of critical literacy in the digital age.

Table 2 presents the results of the post-intervention survey, including mean scores, standard deviations, and modes for each item. These statistics offer a quantitative measure of how students' perceptions and metacognitive awareness changed after engaging with the AI-based learning tool.

Table 2 Results of the post-intervention survey

No.	Question	Mean	SD	Mode
1	AI tutors can provide personalized learning experiences similar to human teachers.	4.12	1.17	5
2	AI tools could enhance my critical reading and analysis abilities.	3.85	1.45	5
3	AI-based literacy training would likely be customized to my specific needs and abilities.	4.12	1.17	5
4	AI could provide literacy instruction to more students, especially in remote areas.	4.05	1.30	5
5	I am excited by the potential benefits of AI for enhancing student literacy.	4.10	1.48	5
6	With guidance from instructors, AI tutors could significantly enhance my learning.	3.95	1.60	5
7	I worry AI may breach the privacy of student data.	3.25	1.75	3
8	I worry AI may reproduce harmful biases in interpreting textual meaning.	3.10	1.69	3
9	AI-based writing tools may fail to grasp context, rhetorical style, and richer meanings.	3.65	1.54	5
10	AI writing assistants could perpetuate biases and style/tone conventions without wisdom.	4.00	1.64	5
11	I fear AI may be used coercively rather than empoweringly in education if not developed carefully.	3.55	1.45	5
12	Over-reliance on AI in education could hinder development of independent thinking.	3.60	1.70	5
13	I am skeptical AI can develop the advanced reasoning needed for true critical thinking.	3.85	1.53	5
14	AI lacks the emotional intelligence and wisdom of human teachers.	3.70	1.55	5
15	AI has inherent limitations compared to human cognition and understanding.	3.40	1.69	5

These results reveal several noteworthy trends:

- **Enhanced Perception of AI's Role in Learning:** Items 1-6 show consistently high mean scores (ranging from 3.85 to 4.12), indicating a positive shift in students' views on AI's potential to enhance personalized learning and critical thinking skills.
- **Metacognitive Awareness:** The high score for item 2 (mean = 3.85) suggests increased recognition of AI's potential to enhance critical reading and analysis abilities, potentially reflecting greater metacognitive awareness.
- **Evolving Conception of Critical Literacy:** Items 3-5 show strong agreement (means > 4.0) with AI's potential to customize literacy training and enhance student literacy, indicating an expanded understanding of critical literacy in the digital age.
- **Ethical Considerations:** While concerns about privacy (item 7) and bias (item 8) have decreased compared to pre-intervention results, students maintain awareness of potential ethical issues (items 10-12).
- **Recognition of AI Limitations:** Items 13-15 reveal that students maintain a nuanced view of AI's capabilities, acknowledging its potential while recognizing its limitations compared to human cognition.

These quantitative results, combined with qualitative insights from the semi-structured interviews, provide a comprehensive picture of how interaction with AI has influenced students' metacognitive processes and their understanding of critical literacy in an AI-augmented learning environment.

3.3. Qualitative Insights

Thematic analysis of the interview data revealed four key themes:

- **AI as a Metacognitive Trigger**
Students reported increased awareness of their thinking processes during AI interaction. For example: "The AI made me think about how I approach reading critically. I realized I often skip important details." (Participant 7)
- **Expanded Conception of Critical Literacy**
Participants expressed a broadened understanding of what it means to be critically literate in the digital age: "I now see that being literate today includes knowing how to effectively use and critically evaluate AI tools." (Participant 13)
- **AI as a Collaborative Tool for Critical Thinking**
Students increasingly viewed AI as enhancing rather than replacing human critical thinking: "Interacting with the AI showed me new dimensions of critical thinking, like considering the biases and limitations of AI-generated analyses." (Participant 22)
- **Ethical Considerations in AI-Augmented Learning**
While privacy concerns decreased, students remained cognizant of potential ethical issues: "I'm less worried about data privacy now, but I think we need to be careful about relying too much on AI for critical analysis." (Participant 9)

The results of this study provide compelling evidence for AI's potential as a catalyst for metacognition and its role in reshaping conceptions of critical literacy in the digital age.

AI as a Metacognitive Trigger

The significant increase in students' recognition of AI's potential to enhance critical reading and analysis abilities (from 3.05 to 3.85) suggests that AI interaction prompted metacognitive reflection. This aligns with Flavell's (1979) theory of metacognition, which posits that novel experiences can trigger metacognitive processes. The AI tool, by challenging students' existing approaches to literary analysis, seems to have functioned as an external trigger for metacognitive experiences.

Qualitative data further support this interpretation, with students reporting increased awareness of their thinking processes during AI interaction. This newfound metacognitive awareness has important implications for education, suggesting that AI tools could be strategically employed to foster deeper, more reflective learning experiences.

Evolving Conceptions of Critical Literacy

The study reveals a significant shift in how students conceptualize critical literacy in the context of AI. The increased agreement that AI could enhance literacy instruction (from 3.55 to 4.05) coupled with qualitative insights suggests an expansion of what students consider to be critical literacy skills.

This evolution aligns with contemporary digital literacy frameworks (e.g., Eshet-Alkalai, 2004) but extends them to explicitly include AI literacy. Students' recognition that being critically literate

now involves the ability to effectively use and evaluate AI tools represents a crucial advancement in preparing learners for an AI-infused world.

AI as a Collaborative Tool for Critical Thinking

The findings challenge the notion of AI as a replacement for human critical thinking. Instead, students increasingly viewed AI as a collaborative tool that could enhance their analytical capabilities. This perspective aligns with the concept of "intelligence augmentation" proposed by Engelbart (1962), suggesting that education should focus on developing students' abilities to effectively collaborate with AI systems.

Ethical Considerations in AI-Augmented Learning

While privacy concerns decreased post-intervention, the persistence of ethical considerations highlights the need for ongoing dialogue about responsible AI use in education. The stability in concerns about AI perpetuating biases (3.8 pre-intervention, 4.0 post-intervention) suggests that students are developing a nuanced understanding of AI's limitations and potential risks.

This awareness presents an opportunity for educators to integrate discussions of AI ethics into curriculum design, fostering critical thinking not just about subject matter, but about the tools used to analyze it.

Implications for Education

These findings have significant implications for educational practice and policy:

- **Intentional Integration of AI:** Educators should consider deliberately incorporating AI tools as catalysts for metacognitive development.
- **Expanding Digital Literacy Curricula:** There's a need to update literacy frameworks to include AI literacy as a core component.
- **Ethical AI Use:** Curriculum designers should incorporate discussions of AI ethics to prepare students for responsible engagement with these technologies.
- **Professional Development:** Educators need training to effectively leverage AI as a tool for fostering metacognition and critical literacy.

4. Conclusion

In conclusion, this study demonstrates AI's potential as a powerful catalyst for metacognitive growth and the expansion of critical literacy skills. As AI continues to permeate educational environments, understanding its impact on students' thinking processes and conceptions of literacy will be crucial for developing pedagogies that prepare learners for the complexities of the digital age.

While this study provides valuable insights, limitations include the short-term nature of the intervention and the focus on a single institution. Future research should explore long-term effects of AI integration on metacognitive development and investigate how these findings generalize across different educational contexts and disciplines.

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