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Cognitive Amplification: Harnessing Artificial Intelligence to Augment Metacognitive Learning Strategies

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Abstract

Objectives: In the realm of education, the integration of Artificial Intelligence (AI) holds promise for enhancing metacognitive learning strategies, which are vital for fostering self-regulated and reflective learning behaviors. This paper explores how Artificial Intelligence (AI) can enhance metacognitive learning strategies, crucial for self-regulated learning. Through 'Cognitive Amplification,' AI offers personalized feedback, schedules, and self-assessment tools to address learners' challenges in deploying these strategies effectively. Understanding AI's role in amplifying cognitive processes is vital for tailored educational interventions, improving engagement and outcomes.

Methods: Using qualitative methods, this study examines participants' experiences with AI tools for metacognitive learning, aiming to identify facilitators and barriers to AI integration in education.

Results: The study reveals a nuanced relationship between digital literacy levels and the impact of AI tools on learning. Low digital literacy participants initially faced frustrations but showed increased motivation with familiarity, while moderate and high literacy participants experienced significant benefits, particularly in self-regulated learning. Addressing diverse digital literacy needs is crucial for optimizing AI tools, with future research focusing on tailored interventions and user interfaces.

Conclusions: Key recommendations emphasize creating user-friendly interfaces, offering thorough onboarding for low digital literacy users, and implementing personalized feedback and structured study schedules, while addressing ethical concerns like data privacy and algorithmic bias to enhance AI-driven learning experiences.

Keywords: Artificial Intelligence, metacognitive strategy, EFL, learning strategy.

التضخيم المعرفي: تسخير الذكاء الاصطناعي لتعزيز استراتيجيات التعلم المعرفي

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ملخّص

الأهداف: يعد دمج الذكاء الاصطناعي في مجال التعليم (AI) واعدًا لتعزيز استراتيجيات التعلم ما وراء المعرفي، والتي تُعَدّ حيوية لتعزيز سلوكيات التعلم ذاتية التنظيم. تستكشف هذه الورقة كيف يمكن للذكاء الاصطناعي أن يعزز استراتيجيات التعلم ما وراء المعرفي، وهو أمر بالغ الأهمية للتعلم المنظم ذاتيًا. من خلال" التضخيم المعرفي"، يقدم الذكاء الاصطناعي تعليقات وجداول زمنية وأدوات تقييم ذاتي مخصصة لمواجهة التحديات التي يواجهها المتعلمون في نشر هذه الاستراتيجيات على نحو فعال. يعد فهم دور الذكاء الاصطناعي في تضخيم العمليات المعرفية أمرًا حيويًا للتدخلات التعليمية المصممة خصيصًا، وتحسين المشاركة والنتائج.

المنهجية: باستخدام الأساليب النوعية، تبحث الدراسة في تجارب المشاركين مع أدوات الذكاء الاصطناعي للتعلم ما وراء المعرفي، بهدف تحديد الميسرين والعوائق التي تحول دون دمج الذكاء الاصطناعي في التعليم.

النتائج: تكشف الدراسة عن علاقة دقيقة بين مستويات المعرفة الرقمية وتأثير أدوات الذكاء الاصطناعي على التعلم. واجه المشاركون ذوو المعرفة الرقمية المنخفضة في البداية إحباطات لكنهم أظهروا حافزًا متزايدًا مع الألفة، وحقق المشاركون ذوو المعرفة المتوسطة والعالية فوائد كبيرة، لا سيما في التعلم المنظم ذاتيًا. تعد تلبية احتياجات المعرفة الرقمية المتنوعة أمرًا بالغ الأهمية لتحسين أدوات الذكاء الاصطناعي، مع تركيز الأبحاث المستقبلية على التدخلات المخصصة وواجهات المستخدم.

التوصية: تؤكد التوصيات على إنشاء واجهات سهلة الاستخدام، وتوفير إعداد شامل للمستخدمين ذوي المعرفة الرقمية المنخفضة، وتنفيذ تعليقات شخصية وجداول دراسية منظمة، مع معالجة المخاوف الأخلاقية مثل خصوصية البيانات والتحيز الخوارزمي لتعزيز تجارب التعلم المعتمدة على الذكاء الاصطناعي. تطوير واجهات الذكاء الاصطناعي سهلة الاستخدام ومسارات التعلم الشخصية، مما يعزز إمكانية الوصول إلى التعليم وفعاليته.

الكلمات المفتاحية: الذكاء الاصطناعي، استراتيجية ما وراء المعرفية، اللغة الإنجليزية كلغة أجنبية، استراتيجية التعلم.

Introduction:

In the rapidly evolving landscape of education, the integration of Artificial Intelligence (AI) stands as a transformative force with far-reaching implications. Amidst the myriad domains touched by its potential, the augmentation of metacognitive learning strategies emerges as a beacon of exploration and innovation. Metacognition, a concept rooted in the profound understanding and monitoring of one's cognitive processes, has long been revered as the cornerstone of effective learning (Flavell, 1976). Its influence on academic achievement and the cultivation of lifelong learning competencies is unequivocal (Brown, 1987).

Recent strides in AI technologies present unprecedented opportunities to revolutionize metacognitive learning strategies. Through the adept utilization of machine learning algorithms, natural language processing techniques, and adaptive learning systems, educators now possess the means to deliver personalized, real-time feedback and tailored support that align precisely with individual cognitive needs (Luckin et al., 2016). These AI-driven interventions hold the promise of nurturing deeper levels of metacognitive awareness and self-regulation among learners, thus optimizing learning outcomes and nurturing essential lifelong learning skills (Van Lehn, 2011).

Nevertheless, the seamless integration of AI into metacognitive learning environments necessitates a meticulous consideration of multifarious factors. Ethical implications, pedagogical principles, and technological affordances must be carefully weighed. While AI-enabled tools hold immense potential to enhance metacognitive learning, they also give rise to legitimate concerns regarding data privacy, algorithmic bias, and the potential erosion of human agency in the learning process (Dillenbourg et al., 2018). Thus, cultivating a nuanced understanding of the intricate interplay between AI technologies and metacognitive learning strategies becomes imperative to harness their benefits while safeguarding against potential risks.

In the rapidly evolving landscape of education, the integration of Artificial Intelligence (AI) stands as a transformative force with far-reaching implications. This paper embarks on a journey to explore the intersection of AI and metacognitive learning strategies, recognizing the importance and necessity of this undertaking in advancing educational practices. By delving into the theoretical underpinnings, empirical evidence, and practical implications of integrating AI within educational contexts, the study aims to provide a comprehensive understanding of how AI can enhance metacognitive learning. Through a multidisciplinary lens that encompasses cognitive psychology, educational technology, and computer science, this research endeavors to illuminate both the opportunities and challenges associated with leveraging AI to augment metacognitive learning strategies. Ultimately, it seeks to contribute to the advancement of educational theory and practice in the digital age, addressing critical gaps and proposing innovative solutions to foster effective and lifelong learning.

Literature review

Metacognition, rooted in the reflective awareness and regulation of one's cognitive processes, stands as a fundamental pillar of learning theory. As delineated by Flavell (1976), it encompasses both metacognitive knowledge, which involves understanding one's cognitive processes, and metacognitive regulation, which pertains to the strategies for monitoring and controlling cognitive activities. This conceptual framework serves as the bedrock for understanding the intricate interplay between cognition and self-awareness.

Building upon this theoretical foundation, recent advancements in Artificial Intelligence (AI) present unprecedented opportunities to scaffold metacognitive development within educational settings. AI technologies offer a multifaceted approach to supporting metacognitive learning strategies. Adaptive learning systems, driven by machine learning algorithms, have showcased their ability to tailor instructional content and feedback to the nuanced cognitive needs of individual learners (Van Lehn, 2011). Such personalized interventions not only enhance metacognitive awareness but also promote the cultivation of self-regulation skills crucial for academic success.

Moreover, natural language processing techniques have revolutionized the analysis of students' reflective writings and discourse patterns, providing educators with valuable insights into their metacognitive processes (D'Mello & Graesser, 2012). This deeper understanding enables targeted interventions aimed at bolstering metacognitive competencies and

fostering deeper levels of cognitive engagement.

Intelligent tutoring systems, equipped with cognitive modeling capabilities, represent another avenue for facilitating metacognitive skill development. Through explicit instruction and guided practice, these systems empower learners to reflect on their learning processes, identify areas for improvement, and employ effective strategies to overcome challenges (Aleven et al., 2009). By simulating human-like interactions and providing tailored support, intelligent tutoring systems serve as invaluable companions in the journey towards metacognitive mastery.

The integration of AI into metacognitive learning environments holds immense promise for educational practice. Educators can harness AI-enabled tools to cultivate a culture of metacognitive reflection and self-regulation in the classroom (Winne & Hadwin, 2001). Furthermore, AI-driven analytics offer educators actionable insights into students' learning behaviors and misconceptions, guiding instructional decision-making and intervention strategies (Baker & Yacef, 2009). However, alongside these opportunities, ethical considerations loom large. Issues surrounding data privacy, algorithmic bias, and equitable access to AI-enabled resources demand careful attention and proactive measures (Blikstein, 2013). Balancing the transformative potential of AI with ethical imperatives is essential to realizing the full benefits of AI in augmenting metacognitive learning strategies and fostering equitable educational opportunities for all learners.

Digital literacy, encompassing the skills and competencies required to effectively navigate, evaluate, and create information using digital technologies, has emerged as a critical component in the educational landscape. Scholarly research highlights the multifaceted nature of digital literacy, integrating cognitive, technical, and socio-emotional dimensions that extend beyond mere technical proficiency (Ng, 2012; Eshet-Alkalai, 2009). This competency is increasingly seen as essential for participation in contemporary society, where digital platforms dominate communication, information retrieval, and problem-solving activities (Spante et al., 2018). Educational frameworks such as the European Digital Competence Framework (DigComp) underscore the need for comprehensive digital literacy education, advocating for the integration of digital skills across curricula to prepare students for the demands of the digital age (Carretero, Vuorikari, & Punie, 2017). However, disparities in access to digital resources and varying levels of digital literacy among different demographic groups pose significant challenges, necessitating targeted interventions and inclusive policies to bridge the digital divide (Van Dijk, 2006; Helsper & Eynon, 2010). Overall, the academic discourse on digital literacy underscores its vital role in fostering critical thinking, digital citizenship, and lifelong learning in an increasingly digital world.

Methodology

This study adopts the qualitative research paradigm to investigate the changes of Chinese college students' learning strategies before and after using AI. Participants were selected from different colleges and universities in China through purposeful sampling to ensure diversity in terms of language ability, academic background and English learning experience (Creswell, 2014). The research team consists of experienced educators and linguists with extensive backgrounds in second language acquisition, artificial intelligence, and qualitative research methods. The team gained a comprehensive understanding of the complexities and artificial intelligence of learning English in a Chinese educational context. This background played a crucial role in structuring the study design, developing relevant interview questions, and ensuring a thorough analysis of the data.

A case study design was employed, incorporating multiple cases to offer a comprehensive description and facilitate a comparative analysis of findings. This approach, as recommended by Hancock et al. (2021), aims to generate insightful perspectives on the identified issue. To achieve qualitative saturation, a sample size of eight to ten is expected to be recruited (Creswell, 2013). Thus, eight EFL learners from Chinese higher education providers, whose demographic information was recorded in Table 1, were selected using purposive sampling, allowing for selecting participants who could provide rich and diverse data (Creswell, 2013). Consent was obtained from the participants, who were also informed about the nature of the study, its purpose, and the confidentiality of their responses.

Table 1. Participants' demographic information

Participants	Gender	Years of college	Digital literacy	major
P1	female	2	Low	English
P2	female	2	Moderate	English
P3	female	2	Low	English
P4	female	2	High	English
P5	male	2	Moderate	English
P6	male	2	Moderate	English
P7	male	2	High	English
P8	male	2	High	English

This paper investigates the level of digital literacy. As for the title design of this part, it mainly draws on the key content of the Global Framework for Digital Literacy issued by UNESCO in 2018 and the specific content of the definition of digital literacy in the Action Program for Promoting Digital Literacy and Skills for All issued by China's Central Cyberspace Administration in November 2021, and is based on the characteristics of college students in their stage. Comprehensively determine the test questions of this part. Therefore, the questions in this part are divided into five dimensions: digital consciousness, digital content creation, digital communication and application, digital security, and digital ethics and norms. In the form of scale questions, respondents can choose suitable options according to their actual situations. This part adopts five-level Likert scale questions, and each statement has five answers: 'very consistent', 'relatively consistent', 'consistent', 'relatively inconsistent' and 'very inconsistent', which are recorded as 5, 4, 3, 2 and 1, respectively. The total score obtained by the respondent can explain the strength and level of his attitude. According to Landell's (2014) benchmark for mean scores, those between 1.00 and 2.33 are designated as 'low level,' scores from 2.34 to 3.66 are identified as 'moderate level,' and mean scores ranging from 3.67 to 5.00 are classified as 'high level.' (Table 2)

Table 2. Mean Score Benchmark by Landell (1977)

Scale	Level
Score 1.00-2.33	Low
Score 2.34-3.66	Moderate
Score 3.67-5.00	High

Data were collected from semi-structured interviews by face to face to answer the questions 'What differences do participants have in their actual experience of using AI to enhance metacognitive learning strategies' and 'What specific metacognitive learning strategies are most effectively supported by artificial intelligence applications?'. An interview protocol was designed to explore participants' use of metacognitive learning strategies as EFL learners, including their motivations, attitudes, and experiences (refer to Appendix A). The collected data was subjected to thematic analysis in NVivo, a software program for qualitative analysis that allows for the identification of patterns and themes in the data. To ensure the reliability of the survey results, the researchers conducted a member examination, peer reporting and reflection.

To manage and mitigate potential biases from prior understandings, several metacognitive strategies were employed. Reflexive practices, such as maintaining reflective journals and conducting regular debriefing sessions, were implemented to discuss possible biases and preconceptions. These practices enhanced the credibility and rigor of the study by ensuring that interpretations were grounded in the participants' perspectives rather than preconceived notions. Additionally, the use of triangulation in data collection and analysis provided a more comprehensive understanding of the phenomena under study. This approach allowed for a richer, more nuanced understanding of the metacognitive learning strategies employed by Chinese college students. By acknowledging and systematically managing prior understandings, the research team enhanced the depth and validity of the study. The insights gained from this research contribute to a more contextualized and culturally responsive understanding of English language learning strategies among Chinese college students, offering valuable implications for educators and policymakers.

Findings

RQ1

Theme 1 Motivation and engagement

Participants with low digital literacy often encountered initial hesitations and challenges when using AI tools. For instance, Participant 1 stated, *'At first, I was really hesitant to use the AI tools because I wasn't confident with technology. But once I started, I found it quite exciting. The AI kept reminding me of my goals, which made me more motivated to stick to my study plan.'* This indicates that despite initial reluctance, the goal-setting features of AI could effectively motivate users once they became familiar with the tools. Conversely, Participant 3 expressed frustration, *'Using AI was a bit challenging for me. I often felt frustrated when I couldn't figure out how to use certain features. This sometimes made me less motivated to continue using the tool, even though I knew it could help.'* This highlights how technical difficulties and a steep learning curve can demotivate users with lower digital literacy, limiting their engagement with the AI tools.

Participants with moderate digital literacy generally found AI applications engaging due to personalized feedback and interactive elements. Participant 2 remarked, *'I found the AI applications to be engaging because they offered personalized feedback. It was like having a tutor who knew exactly where I was struggling. This personalized attention kept me motivated.'* This suggests that AI's ability to provide tailored support can significantly boost motivation. However, Participant 6 noted, *'The AI tools were generally easy to use, but sometimes I felt they were too repetitive. My engagement dropped when the tasks felt monotonous, even if they were meant to help me learn better.'* This points to a potential downside where repetitive tasks can diminish engagement. Participant 5 added, *'What I liked about using AI was the interactive elements, like quizzes and games. These features made learning more fun and kept me engaged for longer periods compared to traditional study methods.'* Interactive and gamified elements appear to be effective in maintaining engagement among these users.

Participants with high digital literacy experienced the most seamless and engaging interaction with AI tools. Participant 4 shared, *'I enjoyed using AI tools because they integrated seamlessly with other digital platforms I use. The instant feedback and progress tracking features were highly motivating and helped me stay on top of my studies.'* This indicates that for digitally literate users, seamless integration and advanced features like progress tracking are key motivators. Participant 7 commented, *'For me, the most engaging part was the adaptive learning paths. The AI could adjust the difficulty based on my performance, which kept the challenges appropriate and kept me motivated to improve.'* This shows that adaptive learning paths that adjust to the user's level can effectively maintain motivation. Lastly, Participant 8 stated, *'The AI's ability to gamify the learning process was fantastic. Earning badges and completing challenges made studying feel less like a chore and more like a game, which significantly boosted my motivation and engagement.'* Gamification elements were particularly effective in enhancing motivation and engagement among these users.

Theme 2 Perceived impact on learning outcomes

Participants with low digital literacy expressed challenges in fully benefiting from AI tools. Participant 1 felt overwhelmed, stating, *'I often felt overwhelmed using the AI tools. While it provided useful feedback, I struggled to interpret it correctly and apply it to my studies.'* This sentiment was echoed by Participant 3, who said, *'The AI seemed to know what I needed to improve, but I wasn't sure how to use the information it gave me.'* These participants acknowledged the potential of AI but faced difficulties in understanding and applying its feedback due to limited digital literacy.

Participants with moderate digital literacy found AI tools helpful in identifying areas for improvement. Participant 2 noted, *'Using AI helped me identify my weak areas more clearly. I could see where I was going wrong, but sometimes it was still challenging to make the necessary adjustments in my study habits.'* Participant 5 appreciated the structured feedback, stating, *'The AI provided a structured way to review my work, which I found really helpful.'* However, they also expressed the need for additional guidance to fully understand and implement the feedback. Participant 6 experienced positive changes in organizational skills, saying, *'I noticed an improvement in my ability to organize my study sessions. The AI's reminders and planning tools made a significant difference, although I occasionally found them intrusive.'* While the AI improved organization, occasional intrusiveness was noted.

Participants with high digital literacy reported significant benefits from AI tools. Participant 4 described the AI as a 'game-changer,' noting, *'It provided real-time feedback that I could immediately act on, which significantly improved my understanding and retention of the material.'* Participant 7 appreciated the personalized feedback, stating, *'I felt that the AI tailored its feedback to my learning style. It was intuitive and made my study sessions more efficient and productive.'* Participant 8 found the progress tracking and instant feedback highly motivating, saying, *'The ability to track my progress and get instant feedback was incredibly motivating. I could see my growth over time, which kept me engaged and focused.'* These participants effectively utilized AI tools, leading to substantial improvements in learning outcomes, engagement, and focus.

Theme 3 Psychological and Emotional Aspects

Participants with low digital literacy expressed mixed feelings regarding the psychological and emotional aspects of using AI for metacognitive learning strategies. While they recognized the potential benefits, such as Participant 1 who mentioned, *'I can see how the AI can help me, but it's frustrating when I can't figure out how to use it effectively,'* there was a sense of frustration and inadequacy in their experience. Participant 3 echoed this sentiment, stating, '*Sometimes, I feel like I'm falling behind because I don't understand how to make the most of the AI's suggestions.'* These participants highlighted feelings of frustration and self-doubt, stemming from their struggle to utilize AI tools effectively.

Participants with moderate digital literacy had a more balanced emotional experience with AI for metacognitive learning strategies. While they appreciated the benefits, such as Participant 2 who said, *'The AI helps me pinpoint where I need to improve, but it can be challenging to implement changes,'* they also expressed occasional frustration. Participant 5 highlighted this, stating, *'There are times when I wish the AI could provide more detailed explanations to help me fully grasp its suggestions.'* Despite occasional frustration, these participants generally felt empowered by the AI's assistance in enhancing their metacognitive learning strategies.

Participants with high digital literacy reported overwhelmingly positive emotional experiences with AI for metacognitive learning strategies. They expressed feelings of confidence and empowerment, as Participant 4 stated, *'The AI has become my go-to tool for improving my study habits. It's like having a personal coach guiding me every step of the way.'* Participant 7 emphasized the emotional satisfaction derived from the personalized nature of AI feedback, saying, *'It's incredibly satisfying to see the AI adapt to my learning style and witness the tangible progress I'm making.'* Participant 8 echoed this sentiment, expressing, *'Using AI for metacognitive learning feels like a partnership where I'm in control of my learning journey.'*

RQ2

Theme 1 Planning strategy

Participants with low digital literacy had mixed experiences with AI in supporting their planning strategies. Participant 1 mentioned, *'I struggle to set up the AI tools properly, so I often miss out on the reminders and planning features it offers.'* This indicates a challenge in leveraging AI effectively due to unfamiliarity with digital tools. Similarly, Participant 3 stated, *'The AI gives good planning advice, but I find it hard to follow through because I'm not used to these kinds of digital schedules.'* Both participants recognized the potential benefits of AI for planning but faced difficulties in fully utilizing these features.

Participants with moderate digital literacy reported more positive experiences with AI in enhancing their planning strategies. Participant 2 highlighted, *'The AI helps me plan my study sessions better by breaking down tasks into manageable chunks.'* This suggests that AI tools effectively support task management for individuals with moderate digital literacy. Participant 5 echoed this sentiment, stating, *'I like how the AI suggests a study schedule based on my progress, though sometimes I need more detailed guidance.'* While they appreciated the AI's planning assistance, they also noted occasional needs for additional support. Participant 6 noted, *'The reminders and deadlines set by the AI keep me on track, but sometimes they can be a bit too frequent, which is distracting.'* This shows that while the AI's planning tools were generally helpful, the frequency of notifications could sometimes be overwhelming.

Participants with high digital literacy reported significant benefits from AI in enhancing their planning strategies.

Participant 4 remarked, *'The AI's planning tools are fantastic. It helps me organize my entire study schedule efficiently and adapt it based on my progress.'* This indicates a high level of comfort and effectiveness in using AI for planning. Participant 7 added, *'I love how the AI tailors its planning advice to fit my study habits, making my preparation more systematic and less stressful.'* Participant 8 expressed similar satisfaction, stating, *'Using AI for planning has revolutionized how I approach my studies. I can track my progress in real-time and adjust my plans accordingly.'* These participants demonstrated that high digital literacy enables the effective use of AI planning tools, resulting in more structured and less stressful study experiences.

Theme 2 Monitoring strategy

Participants with low digital literacy faced challenges in utilizing AI for monitoring their learning effectively. Participant 1 noted, *'I find it difficult to understand the AI's feedback on my progress, so I'm not sure if I'm improving.'* This suggests that while AI provides useful feedback, the participant's low digital literacy hinders their ability to interpret and act on it. Similarly, Participant 3 shared, *'The AI shows me my performance metrics, but I don't really know how to use this information to monitor my learning.'* These participants acknowledged the potential of AI for monitoring but struggled to leverage it due to limited digital skills.

Participants with moderate digital literacy had more success in using AI for monitoring their learning, though they still encountered some challenges. Participant 2 mentioned, *'The AI helps me see where I'm falling behind, but sometimes I need more detailed explanations to understand the feedback fully.'* This indicates that while the AI's monitoring capabilities are beneficial, additional support is sometimes necessary. Participant 5 stated, *'I appreciate how the AI tracks my progress over time and highlights areas for improvement, but occasionally I find the feedback too generic.'* Participant 6 added, *'The AI's monitoring tools are useful for keeping track of my learning goals, though I sometimes need reminders to check the feedback regularly.'* This shows that AI helps in tracking progress, but consistency in engaging with the feedback can be an issue.

Participants with high digital literacy reported significant advantages in using AI for monitoring their learning. Participant 4 explained, *'The AI's real-time feedback is incredibly helpful for keeping track of my progress and adjusting my study strategies accordingly.'* This highlights the effectiveness of AI in providing timely and actionable feedback for monitoring learning. Participant 7 stated, *'I love how the AI customizes its feedback to my learning patterns, which makes it easier to understand and apply the insights.'* Participant 8 echoed this sentiment, sharing, *'The ability to monitor my progress continuously with the AI has kept me more engaged and motivated. I can see my growth and areas that need more attention clearly.'* These participants demonstrated that high digital literacy enables them to fully utilize AI's monitoring capabilities, resulting in better engagement and targeted improvements in their learning strategies.

Theme 3 Evaluation strategy

Participants with low digital literacy encountered difficulties in effectively using AI for evaluation purposes. Participant 1 stated, *'I know the AI gives me feedback on my work, but I often don't understand how to evaluate it properly.'* This highlights the challenge of interpreting AI feedback due to limited digital literacy. Similarly, Participant 3 expressed, *'The AI points out my mistakes, but I'm not sure how to use this information to evaluate my progress.'* Both participants recognized the AI's potential but struggled to use it effectively for self-evaluation.

Participants with moderate digital literacy experienced both benefits and challenges when using AI for evaluation. Participant 2 mentioned, *'The AI helps me see what I need to improve, but sometimes the feedback is too vague for me to evaluate my work thoroughly.'* This indicates that while AI assists in identifying areas of improvement, the clarity of feedback can be an issue. Participant 5 stated, *'I find the AI's evaluations useful, especially when it breaks down my performance into specific areas, but I occasionally need more detailed explanations to fully understand my progress.'* Participant 6 noted, *'The AI's evaluation tools are helpful for assessing my learning outcomes, although I sometimes need reminders to revisit the feedback and reflect on it.'* This shows that while AI aids in evaluation, the consistency in engaging with the feedback remains a challenge.

Participants with high digital literacy reported substantial benefits from using AI for evaluation strategies. Participant 4 remarked, *'The AI's detailed feedback allows me to evaluate my strengths and weaknesses accurately, helping me focus on areas that need improvement.'* This highlights the AI's effectiveness in providing actionable insights for self-evaluation. Participant 7 added, *'I appreciate how the AI customizes its evaluations to my learning style, making it easier for me to understand and act on the feedback.'* Participant 8 shared a similar positive experience, stating, *'Using AI for evaluation has significantly improved my ability to self-assess. The real-time feedback and progress tracking keep me motivated and aware of my learning journey.'* These participants demonstrated that high digital literacy enables them to fully utilize AI's evaluation capabilities, leading to more accurate self-assessment and targeted learning improvements.

Discussion

The findings suggest that AI tools have varying impacts on motivation and engagement across different levels of digital literacy. Participants with low digital literacy experienced initial hesitations and frustrations, which is consistent with previous research indicating that technological proficiency significantly influences user engagement with digital tools (Johnson et al., 2019). Participant 1's shift from hesitation to motivation after becoming familiar with AI tools highlights the potential for adaptive learning technologies to enhance engagement, this shift highlights the potential for adaptive learning technologies to enhance engagement, as these tools can provide personalized learning experiences that adjust to the user's progress and needs (Hwang & Fu, 2020). Such adaptive features can help users overcome initial barriers, leading to greater motivation and engagement over time. Conversely, Participant 3's frustration underscores the importance of user-friendly interfaces and comprehensive onboarding processes to mitigate the steep learning curves that can demotivate less digitally literate users. User-friendly interfaces can make technology more accessible, reducing the cognitive load required to interact with the tools (Kim et al., 2021). Comprehensive onboarding processes, including tutorials and step-by-step guides, can help users become comfortable with new technologies, thus mitigating the initial hesitations and frustrations that might otherwise impede their engagement and motivation.

Participants with moderate digital literacy generally found AI applications engaging due to personalized feedback and interactive elements. This aligns with studies by Lai and Bower (2019), which found that personalized feedback enhances learner engagement by addressing individual needs. Participant 2's experience of AI as a personalized tutor supports the notion that adaptive learning technologies can replicate one-on-one tutoring benefits (VanLehn, 2011). Personalized feedback allows learners to receive immediate, relevant input on their progress, which can significantly enhance their engagement by making the learning experience more responsive and tailored to their specific needs. However, Participant 6's observation about the repetitiveness of AI tasks suggests a need for balancing personalization with variety to maintain long-term engagement, a point also noted by researchers exploring gamification in education (Dicheva et al., 2015), According to Dicheva, they argued that incorporating elements of variety and novelty can sustain learner interest and motivation over extended periods. Therefore, while personalized feedback is crucial for engaging learners, it must be complemented with diverse and stimulating activities to prevent monotony and disengagement.

High digital literacy participants reported seamless integration and advanced features as key motivators. This is corroborated by previous findings that digitally literate users benefit most from the sophisticated capabilities of AI tools, such as instant feedback and progress tracking (Baker et al., 2014). Participant 7's appreciation for adaptive learning paths and Participant 8's positive response to gamification elements highlight the effectiveness of these features in maintaining motivation and engagement, echoing conclusions from studies on adaptive learning technologies (Woolf, 2010), Adaptive learning paths allow for personalized, dynamic adjustments to the learning process, making it more efficient and aligned with the user's needs. Gamification elements, such as rewards and progress tracking, can enhance motivation by making the learning process more enjoyable and engaging (Huang & Soman, 2013).

The perceived impact of AI tools on learning outcomes also varied with digital literacy levels. Participants with low digital literacy struggled to fully benefit from AI tools due to difficulties in understanding and applying feedback, as evidenced by Participant 1 and Participant 3. This finding is consistent with research indicating that low digital literacy can

hinder effective use of educational technologies (Zhang et al., 2018). The need for clearer, more accessible feedback mechanisms is crucial for these users, aligning with recommendations from studies emphasizing user-friendly design in educational software (Spector et al., 2016).

Participants with moderate digital literacy found AI tools helpful in identifying areas for improvement but noted challenges in implementing feedback. This observation aligns with studies by Shute and Towle (2018), which suggest that while AI can diagnose learning gaps effectively, additional scaffolding is often required to help learners act on this information. Participant 5's appreciation for structured feedback indicates that AI can enhance learning organization, a benefit also highlighted in studies on structured learning environments, which emphasizes the advantages of structured learning environments in promoting better learning outcomes. (Azevedo & Hadwin, 2005). However, the occasional intrusiveness of AI tools noted by Participant 6 suggests a need for balanced feedback delivery to avoid overwhelming users. This points to the necessity of a balanced approach in delivering AI feedback, ensuring it is supportive without being disruptive. This balance is crucial to prevent users from feeling overwhelmed, thus maintaining the effectiveness of AI as a learning aid.

High digital literacy participants reported significant benefits from AI tools, including real-time feedback, personalized learning paths, and progress tracking. This aligns with research by Roll and Wylie (2016), which highlights the potential of AI to enhance self-regulated learning by providing timely, actionable insights. Participant 4's description of AI as a "game-changer" and Participant 7's positive experience with personalized feedback underscore the transformative potential of AI for digitally proficient learners. These findings support the view that high digital literacy enables users to fully leverage the advanced features of AI tools, leading to substantial improvements in learning outcomes (Aleven et al., 2016).

The psychological and emotional aspects of using AI for metacognitive learning strategies were particularly pronounced among participants with low digital literacy. Feelings of frustration and inadequacy, as expressed by Participant 1 and Participant 3, highlight the emotional barriers that can impede effective AI use. This aligns with findings by Järvelä and Hadwin (2013), which emphasize the emotional challenges faced by learners struggling with new technologies. Addressing these emotional barriers through supportive interfaces and user education could enhance the effectiveness of AI tools for these users.

Participants with moderate digital literacy had a more balanced emotional experience, feeling both empowered by AI's assistance and occasionally frustrated by its limitations. Participant 2's and Participant 5's experiences reflect the dual nature of AI in education: it can significantly aid learning but may also cause frustration if feedback is unclear or insufficiently detailed. This aligns with research on the importance of detailed, comprehensible feedback for maintaining learner motivation and emotional well-being (Winne & Hadwin, 2001). When feedback is clear and informative, it helps learners understand their progress and how to improve, thereby enhancing their motivation and emotional satisfaction. Conversely, unclear or insufficient feedback can lead to confusion and frustration, undermining the learning process and affecting the learner's emotional state. Thus, ensuring that AI tools provide high-quality, detailed feedback is crucial for fostering a positive and productive learning experience.

High digital literacy participants reported overwhelmingly positive emotional experiences, feeling confident and empowered by AI tools. This is consistent with studies indicating that digital literacy enhances user confidence and reduces technology-related anxiety (Tsai et al., 2019). Participant 4's and Participant 7's descriptions of AI as a supportive, adaptive partner in their learning journey highlight the potential of AI to foster positive emotional responses when users are proficient with digital tools. This supports the view that enhancing digital literacy is key to maximizing the psychological and emotional benefits of AI in education (Lajoie, 2008).

The research findings reveal a nuanced interplay between digital literacy levels and the effectiveness of AI applications in supporting metacognitive learning strategies, specifically planning, monitoring, and evaluation. Participants' experiences with AI in planning varied significantly based on their digital literacy. Those with low digital literacy struggled to effectively use AI due to unfamiliarity with digital tools, reflecting Aleven's (2019) assertion on the importance of technological proficiency. However, increased motivation was reported once participants became familiar with the tools,

suggesting potential benefits of adaptive learning technologies, as noted by Hwang and Fu (2020).

Participants with moderate digital literacy found AI more beneficial, appreciating its ability to break down tasks and provide structured study schedules, aligning with Lai and Bower's (2019) findings on personalized feedback. AI's capacity to tailor feedback and schedules to individual learners' needs helps them manage their study efforts more efficiently and effectively. However, despite recognizing these benefits, participants also noted that they sometimes needed more detailed guidance from the AI. This need suggests that while AI tools are helpful, there is room for improvement in the depth and clarity of the feedback provided. Additionally, participants mentioned that frequent notifications from AI tools could be distracting. This observation echoes insights from Dicheva et al. (2015), who discuss the importance of balance in AI design. To be truly effective, AI tools must deliver feedback and notifications in a manner that supports learning without becoming intrusive or overwhelming.

High digital literacy participants experienced substantial benefits, effectively using AI to plan and organize their studies. They reported that AI tools revolutionized their study approaches, consistent with Baker et al.'s (2021) findings on the advantages for digitally literate users. This group's ability to adapt AI tools to their study habits supports Woolf's (2010) and Huang and Soman's (2013) conclusions on the effectiveness of adaptive learning technologies and gamification elements. Woolf's research emphasizes how adaptive learning technologies can personalize educational experiences, making them more effective and engaging for learners. Similarly, Huang and Soman's work on gamification illustrates how game-like elements can enhance motivation and engagement in learning activities.

The ability to monitor learning with AI was also influenced by digital literacy levels. Low digital literacy participants found it challenging to understand and act on AI feedback, aligning with Zhang et al.'s (2023) findings on the hindrance posed by low digital literacy. This underscores the need for clearer feedback mechanisms, as recommended by Spector et al. (2014). Moderate digital literacy participants found AI helpful in highlighting areas for improvement but occasionally needed more detailed explanations, resonating with Shute and Towle's (2018) research on diagnosing learning gaps and Azevedo and Hadwin's (2005) emphasis on structured learning environments.

High digital literacy participants reported significant advantages, with AI providing timely and actionable feedback that enhanced self-regulated learning. This positive experience aligns with the findings of Roll and Wylie (2016), who emphasize the potential of AI to significantly improve self-regulated learning. According to their research, AI can provide critical support in the form of real-time feedback and personalized guidance, which are essential components for effective self-regulation in learning contexts. However, Roll and Wylie also highlighted the importance of digital literacy in maximizing these benefits, as the ability to effectively use AI tools is closely linked to one's proficiency with digital technologies.

The effectiveness of AI in supporting evaluation strategies also varied with digital literacy. Low digital literacy participants struggled to interpret and act on AI feedback, consistent with Järvelä and Hadwin's (2013) findings on the emotional barriers faced by learners struggling with new technologies. Moderate digital literacy participants experienced mixed benefits, finding AI helpful in identifying areas for improvement but sometimes needing more detailed feedback, as identified by Winne and Hadwin (2013). High digital literacy participants reported substantial benefits from AI's evaluation tools, appreciating the detailed feedback that facilitated accurate self-assessment and targeted improvements, supporting Aleven et al.'s (2016) findings on the transformative potential of AI.

Conclusion

In conclusion, this study has revealed a nuanced relationship between digital literacy levels and the impact of AI tools on motivation, engagement, and metacognitive learning strategies. Low digital literacy participants faced initial hesitations and frustrations, highlighting the crucial role of user-friendly interfaces and comprehensive onboarding processes. However, once familiarized with AI tools, they demonstrated increased motivation, suggesting the potential benefits of adaptive learning technologies. Moderate digital literacy participants found AI applications engaging, particularly appreciating personalized feedback and structured study schedules. Nonetheless, they noted occasional challenges in implementing feedback and the need for balanced notification systems. High digital literacy participants reported significant

benefits, leveraging AI tools to revolutionize their study approaches and enhance self-regulated learning. Their positive emotional experiences underscore the importance of digital literacy in maximizing the potential of AI for education.

The findings underscore the importance of digital literacy as a moderating factor in the effectiveness of AI tools in educational settings. This study expands on existing theories by demonstrating how digital literacy influences user experience and outcomes when interacting with AI-driven educational technologies. Incorporating digital literacy into theoretical models of AI-enhanced education provides a more comprehensive understanding of its role in optimizing metacognitive learning strategies.

From a practical standpoint, the study emphasizes the necessity of designing AI tools that cater to users with varying levels of digital literacy. Educators and developers must consider creating user-friendly interfaces and comprehensive onboarding processes to support users with low digital literacy. Moderate digital literacy participants benefit from personalized feedback and structured study schedules, although they require balanced notification systems to implement feedback effectively. High digital literacy participants, who leverage AI tools to enhance self-regulated learning, highlight the potential for AI to revolutionize study approaches. Addressing the diverse needs of users across different digital literacy levels is crucial for optimizing the effectiveness of AI tools in supporting metacognitive learning strategies.

Future research should focus on developing tailored interventions and user interfaces that enhance the accessibility and usability of AI tools for all learners. Investigations could explore specific strategies to bridge the digital literacy gap and examine the long-term impact of AI-enhanced metacognitive strategies on academic achievement and lifelong learning competencies. Additionally, studies could assess the scalability and adaptability of AI interventions across different educational contexts and populations.

This study underscores the importance of addressing diverse digital literacy levels to optimize the effectiveness of AI tools in supporting metacognitive learning strategies. Key recommendations include developing user-friendly interfaces and providing comprehensive onboarding processes to aid users with low digital literacy. Personalized feedback mechanisms and structured study schedules are essential, along with balanced notification systems to prevent cognitive overload. Promoting digital literacy through educational programs can empower learners to maximize AI tools' benefits. Additionally, it is crucial to address ethical concerns, such as data privacy, algorithmic bias, and preserving human agency in AI-driven learning environments.

The study's limitations include potential bias in self-reported data and the limited generalizability of findings due to the specific participant sample. Future studies should employ diverse methodologies, including longitudinal designs, to validate and extend the current findings. Additionally, exploring the impact of AI tools in varied educational contexts and among different demographic groups would provide a more comprehensive understanding of their effectiveness.

Overall, this research contributes to the advancement of educational theory and practice in the digital age, highlighting the critical role of digital literacy in harnessing the potential of AI to support metacognitive learning strategies. By addressing the diverse needs of users, educators and developers can enhance the accessibility and effectiveness of AI tools, fostering effective and lifelong learning.

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