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Exploring Stem Learners' Perceptions of Artificial Intelligence in Personalizing Metacognitive Strategy Development

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This research paper investigates the perceptions of STEM (Science, Technology, Engineering, and Mathematics) learners regarding the integration of artificial intelligence (AI) in personalizing metacognitive strategy development. Metacognition, the awareness and regulation of one's own cognitive processes, plays a vital role in STEM education for enhancing problem-solving skills, critical thinking, and self-directed learning. With advancements in AI-driven technologies, there is growing interest in leveraging AI to personalize metacognitive support for individual learners. However, understanding how STEM learners perceive and engage with AI-driven interventions in their metacognitive development is essential for effective implementation. Through purposeful sampling and semi-structured interviews, this qualitative study explores the attitudes, experiences, and concerns of STEM learners regarding AI-driven personalized metacognitive support. Thematic analysis of interview data reveals diverse perspectives, ranging from acknowledgment of AI's potential benefits to skepticism about its effectiveness and ethical implications. The findings highlight the importance of considering learners' backgrounds, experiences, and ethical considerations in designing and implementing AI-driven interventions for metacognitive development in STEM education.

Keywords: STEM Education, Artificial Intelligence, Metacognition, Personalized Learning, Educational Technology.

In recent years, the integration of artificial intelligence (AI) technologies in educational settings has garnered increasing attention for its potential to transform learning experiences and outcomes across various domains (Luckin et al., 2016; Siemens & Long, 2011). Particularly in science, technology, engineering, and mathematics (STEM) education, where the cultivation of metacognitive skills is paramount, AI holds promise in personalizing learning experiences to meet the diverse needs of learners (Azevedo & Witherspoon, 2009; Woolf et al., 2010). Metacognition, the awareness and regulation of one's own thinking processes, plays a crucial role in fostering deep understanding, problem-solving proficiency, and self-directed learning in complex subject areas such as STEM (D'Mello &Graesser, 2012; VanLehn, 2011).

Traditionally, metacognitive development has been approached through standardized interventions and instructional strategies aimed at enhancing students' awareness and control of their cognitive processes (Anderson et al., 1995; Corbett & Anderson, 1995). However, with advancements in AI-driven adaptive learning systems, there emerges an opportunity to tailor metacognitive support to individual learners' cognitive styles, preferences, and prior knowledge (Arroyo et al., 2014; Pardos& Heffernan, 2010). AI-powered platforms have the potential to analyze vast datasets of learner interactions and provide personalized feedback, prompts, and scaffolding in real-time, fostering a more individualized and effective learning experience (Aleven et al., 2009; Baker et al., 2010).

Moreover, recent literature (Zhang & Ye, 2023; Chen & Wang, 2022; Smith & Jones, 2021; Li & Wu, 2020; Kim & Lee, 2020) emphasizes the growing significance of AI in STEM education and underscores the need for further exploration into its impact on metacognitive development. These studies provide valuable insights into the opportunities and challenges posed by AI-driven interventions in personalized metacognitive support, contributing to the ongoing discourse on the intersection of technology and learning in STEM fields.

The convergence of artificial intelligence (AI) and education, particularly in enhancing metacognitive strategy development among STEM learners, has become a burgeoning field of study. Metacognition, a critical component of effective learning, involves self-awareness and self-regulation of one's cognitive processes. In STEM education, fostering metacognitive skills can significantly enhance problem-solving abilities, conceptual understanding, and overall academic performance. This literature review synthesizes recent advancements in AI applications in education, focusing on intelligent tutoring systems, adaptive learning environments, and the implications for metacognitive development.

Aleven et al. (2009) introduced a novel paradigm for intelligent tutoring systems, highlighting the potential of example-tracing tutors to provide personalized and adaptive learning experiences. Their study demonstrated significant improvements in student performance, underscoring the efficacy of AI-driven interventions in educational settings. Similarly, Anderson et al. (1995) emphasized the lessons learned from cognitive tutors, which leverage AI to adapt instruction based on individual learner needs, thereby facilitating deeper understanding and retention of STEM concepts.

Arroyo et al. (2014) explored a multimedia adaptive tutoring system for mathematics that addresses cognition, metacognition, and affect. Their findings revealed that integrating metacognitive support into AI-driven learning environments can enhance students' ability to regulate their learning processes, leading to better academic outcomes. This is corroborated by Azevedo and Witherspoon (2009), who found that self-regulated learning with hypermedia is significantly influenced by prior domain knowledge, highlighting the importance of personalized learning pathways in fostering metacognitive skills.

D'Mello and Graesser (2012) examined the dynamics of affective states during complex learning, suggesting that AI systems capable of detecting and responding to learners' emotional states can provide timely metacognitive support. This aligns with Luckin et al. (2016), who argued for the integration of AI in education to create intelligent learning environments that adapt to the cognitive and emotional needs of students.

In a longitudinal study, Ma and Chan (2014) investigated the relationships between information and communication technology (ICT), self-directed learning, and academic achievement. Their results indicated that AI-driven educational technologies can enhance self-regulated learning and academic performance, particularly in STEM disciplines. Pardos and Heffernan (2010) further emphasized the role of Bayesian networks in modeling individualization in intelligent tutoring systems, which can dynamically adapt to learners' evolving needs and promote metacognitive development.

Calvo and D'Mello (2010) provided an interdisciplinary review of affect detection models and methods, arguing that AI systems capable of understanding and responding to learners' emotional states can provide comprehensive metacognitive support. Conati and Maclaren (2009) empirically evaluated a probabilistic model of user affect, demonstrating the potential of AI in adapting instructional strategies based on learners' emotional responses.

Corbett and Anderson (1995) introduced the knowledge tracing model, which uses AI to track learners' acquisition of procedural knowledge and provide personalized feedback. This model has been instrumental in the development of intelligent tutoring systems that support metacognitive development by adapting to learners' progress and providing timely interventions.

In the integration of AI in education holds significant promise for enhancing metacognitive strategy development among STEM learners. By leveraging intelligent tutoring systems, adaptive learning environments, and affect-sensitive technologies, educators can create personalized and supportive learning experiences that promote self-regulation, engagement, and academic success. However, ongoing research is needed to address challenges related to algorithmic bias, data privacy, and the scalability of AI-driven interventions to ensure their equitable and effective implementation in diverse educational contexts.

Key Concepts

Metacognition in STEM Education: Metacognition, often described as "thinking about thinking," is fundamental in STEM learning, enabling learners to monitor, regulate, and adapt their cognitive processes effectively (Flavell, 1979). Essential metacognitive skills such as problem-solving, critical thinking, and self-reflection are vital for navigating complex tasks and concepts within STEM education (Mayer, 2019).

Role of Artificial Intelligence in Education: Artificial intelligence (AI) encompasses various technologies and approaches, including machine learning and intelligent tutoring systems, with the potential to revolutionize educational practices (Luckin et al., 2019). AI-driven interventions offer personalized learning experiences, adaptive feedback, and data-driven insights, empowering educators to tailor instruction to individual learner needs and preferences (Siemens & Long, 2011).

AI-Driven Interventions for Metacognitive Support: Recent research explores AI's application in supporting metacognitive development among STEM learners through interventions like intelligent tutoring systems and learning analytics platforms (Azevedo & Witherspoon, 2009). These interventions leverage AI algorithms to provide real-time feedback, adaptive scaffolding, and personalized learning pathways, enhancing learners' metacognitive skills and problem-solving abilities (Arroyo et al., 2014).

Challenges and Considerations: Despite their promise, AI-driven interventions face challenges such as algorithmic bias, data privacy concerns, and ethical implications (Baker et al., 2010). Questions regarding efficacy, scalability, and sustainability also require thorough investigation to ensure the responsible implementation of AI technologies in educational settings (VanLehn, 2011).

Based on the review of literature the following research gaps have been identified. Despite advancements in the integration of artificial intelligence (AI) in educational contexts, several research gaps remain in understanding its implications for metacognitive development among STEM learners. Key research gaps identified in this study include:

1. Limited Understanding of Learner Perspectives: There is a paucity of research examining STEM learners' perceptions and experiences with AI-driven interventions aimed at enhancing metacognitive skills. Existing studies often focus on the efficacy of AI technologies from a pedagogical perspective, overlooking the nuanced attitudes and beliefs of learners towards these interventions.

2. Effectiveness and Ethical Concerns: While AI holds promise in supporting personalized metacognitive strategy development, there is a lack of empirical evidence regarding its effectiveness in real-world educational settings. Additionally, ethical considerations such as data privacy, algorithmic bias, and learner autonomy have not been adequately addressed in the literature, warranting further investigation.

3. Contextual Factors Influencing Adoption: The role of contextual factors, such as educational background and technology experience, in shaping STEM learners' perceptions of AI-driven interventions remains underexplored. Understanding how individual characteristics and prior experiences influence attitudes towards AI technologies is essential for designing inclusive and effective interventions.

4. Gap between Research and Practice: Despite growing interest in AI-driven educational technologies, there is often a disconnect between research findings and their implementation in practice. Bridging this gap requires a deeper understanding of the practical challenges and considerations involved in integrating AI into educational settings.

Need and Significance of the study

In the rapidly evolving landscape of education, there exists a pressing need to explore the intersection of artificial intelligence (AI) and metacognitive development among learners in science, technology, engineering, and mathematics (STEM) fields. As educational institutions increasingly embrace AI-driven technologies to enhance learning experiences, it becomes imperative to understand how these innovations impact learners' metacognitive skills. However, there is a notable gap in the literature concerning STEM learners' experiences and perceptions of AI-driven interventions aimed at personalizing metacognitive strategy development. By addressing this gap, the study aims to fill a critical void in understanding how AI can be leveraged to support metacognitive development among STEM learners. Furthermore, given the ethical implications inherent in the integration of AI in educational contexts, there is a need to explore learners' attitudes towards these technologies to ensure responsible implementation practices. Thus, the study not only addresses a significant research gap but also provides timely insights that can inform educational practices, policy decisions, and future research endeavors in the realm of STEM education.

This study holds significant importance in several key areas of educational practice and research. Firstly, by delving into STEM learners' experiences and perceptions of artificial intelligence (AI) technologies aimed at enhancing metacognitive skills, it provides valuable insights that can inform the design and implementation of AI-driven interventions tailored to meet the diverse needs of learners in science, technology, engineering, and mathematics (STEM) fields. Understanding the effectiveness and challenges of these interventions is paramount for improving learning outcomes in STEM education. Additionally, exploring STEM learners' attitudes towards the ethical implications of AI usage in educational contexts is crucial for promoting responsible implementation practices and addressing potential concerns related to data privacy, algorithmic bias, and learner autonomy. The findings of this study can provide evidence-based recommendations for policymakers and educational stakeholders to guide policy decisions regarding the integration of AI technologies in educational settings, ensuring alignment with ethical principles and learner needs. Furthermore, by addressing existing research gaps and contributing new insights into the role of AI in supporting metacognitive development among STEM learners, the study advances the broader body of knowledge in educational psychology and technology-enhanced learning.

Objectives

- To explore STEM learners' experiences and perceptions of artificial intelligence (AI) technologies in enhancing metacognitive skills.
- To investigate the effectiveness and challenges of AI-driven interventions in supporting personalized metacognitive strategy development among STEM learners.
- To examine STEM learners' attitudes towards the ethical implications of AI usage in educational contexts and provide recommendations for the responsible implementation of AI-driven metacognitive support.

Themes of Interest

Effectiveness of AI-Driven Interventions: This variable encompasses themes related to STEM learners' perceptions of the effectiveness, utility, and impact of AI-driven interventions in supporting metacognitive strategy development.

Challenges and Concerns: This variable captures themes related to challenges, limitations, and ethical considerations associated with the integration of AI in personalized metacognitive support for STEM learners.

Contextual Factors

Educational Background: This variable reflects contextual factors such as educational level, prior knowledge, and academic experiences of STEM learners, which may influence their perceptions and responses to AI-driven interventions.

Technology Experience: This variable considers STEM learners' familiarity with technology and digital tools, which may shape their interactions and engagement with AI-enabled interventions in metacognitive development.

Ethical Considerations: This variable explores STEM learners' attitudes towards the ethical implications of AI usage in educational settings, including concerns related to data privacy, algorithmic bias, and learner autonomy, which may influence their acceptance and adoption of AI-driven interventions.

Method

Design:

This study adopts a qualitative approach to delve into STEM learners' perceptions of AI's role in personalizing metacognitive strategy development.

Participants:

The study employs purposive sampling to select STEM learners with prior exposure to AI-driven metacognitive interventions.

Data Collection:

Semi-structured interviews are conducted using an interview protocol to elicit participants' experiences and attitudes towards AI-driven interventions.

Analysis:

Thematic analysis of interview transcripts is employed, involving coding, theme development, and data management facilitated by qualitative software.

Sample Size

The study includes a sample of 30 STEM students, providing a diverse range of perspectives and experiences for analysis.

Data analysis

Table 1.1: Gender Distribution

Gender	Frequency	Percent	Valid Percent	Cumulative Percent
Male	13	43.30%	43.30%	43.30%
Female	17	56.70%	56.70%	100.00%
Total	30	100.00%	100.00%	100.00%

The table 1.1 delineates the gender distribution within a sample population of 30 individuals. It highlights that females constitute the majority, comprising 56.70% of the total sample, equivalent to 17 individuals. Conversely, males represent 43.30% of the surveyed population, comprising 13 individuals.

Table 1.2: STEM Field Distribution

STEM Field	Frequency	Percent	Valid Percent	Cumulative Percent
S&T	16	53.30%	53.30%	53.30%
E	8	26.70%	26.70%	80.00%
M	6	20.00%	20.00%	100.00%
Total	30	100.00%	100.00%	100.00%

Table 1.2 presents the distribution of individuals across different fields within STEM (Science, Technology, Engineering, and Mathematics). Among the total surveyed population of 30 individuals, the majority, constituting 53.30%, are engaged in Science and Technology (S&T) fields. Engineering (E) fields follow, with 26.70% of the population, accounting for 8 individuals. Mathematics (M) fields have the smallest representation, with 20.00% of the population, totalling 6 individuals.

Table 1.3: Technology Experience Level Distribution

Techno logy	Experience Level	Frequency Percent (%)	Valid Percent (%)	Cumulative Percent
High	12	40.00%	40.00%	40.00%
Moderate	10	33.30%	33.30%	73.30%
Low	8	26.70%	26.70%	100%
Total	30	100.00%	100.00%	

The distribution depicted in Table 1.3 on technology experience levels reveals a diverse range of proficiencies among the surveyed individuals. The substantial proportion of individuals (40.00%) classified under the high experience level suggests a significant segment of the population is well-versed and adept in utilizing technology. This may imply a tech-savvy cohort capable of leveraging advanced digital tools and platforms effectively. Moreover, the moderate experience level, encompassing 33.30% of the population, indicates a sizable group with a reasonable degree of technological competence, albeit potentially requiring further training or support to maximize their capabilities fully. Conversely, the 26.70% of individuals categorized under the low experience level signal a segment of the population in need of additional assistance or training to enhance their technological proficiency. This distribution underscores the importance of tailored approaches to technology integration and education, accommodating varying skill levels to ensure inclusivity and efficiency in leveraging technology across different contexts.

Table 1.4: Themes and Perspectives on AI-driven Interventions

Theme	Frequency	Percent	Valid Percent	Cumulative Percent
Effectiveness of AI-Driven Interventions	15	33.30%	33.30%	33.30%
Challenges and Concerns	17	37.80%	37.80%	71.10%
Contextual Factors Influencing Perceptions	13	28.90%	28.90%	100.00%
Total	45	100.00%	100.00%	100.00%

The data presented in Table 1.4 provides a comprehensive insight into the perceptions and discussions surrounding AI-driven interventions among the surveyed population. Notably, although the sample size remains consistent at 30 individuals, the total frequency across themes exceeds this number, amounting to 45. This discrepancy arises from respondents being afforded the opportunity to select multiple themes, indicating a rich diversity of viewpoints within the sample. Despite this variability, several key findings emerge: a significant proportion of respondents (33.30%) focused on evaluating the effectiveness of AI applications, demonstrating a keen interest in understanding their real-world impacts and outcomes. Furthermore, a prevalent theme (37.80%) centered on concerns and challenges associated with AI adoption, indicating widespread apprehension regarding ethical, technical, and societal implications. Discussions within this domain likely encompassed a range of issues, including algorithmic biases, privacy concerns, and potential socioeconomic repercussions. Additionally, a substantial number of respondents (28.90%) explored contextual factors shaping perceptions of AI, highlighting the multifaceted nature of influences such as socio-cultural norms, economic dynamics, and organizational frameworks. These insights underscore the complexity of navigating the AI landscape and emphasize the importance of fostering informed discourse and ethical frameworks to ensure responsible and inclusive AI deployment.

Insights from student interviews

STEM students offered a spectrum of experiences and viewpoints regarding AI-driven interventions. Several students noted the benefits of personalized learning facilitated by AI tutors, citing instances where adaptive feedback and tailored practice exercises enhanced their understanding of challenging concepts. One student mentioned, “The AI tutor in my chemistry class helped me identify gaps in my understanding and provided targeted practice problems, which improved my performance.”

Conversely, some students expressed reservations about the potential drawbacks of AI technologies in education. Concerns centred around the perceived loss of human interaction and the need for personalized support. A student remarked, “While the AI tutor was helpful, I missed the individualized guidance and support from a human instructor. There’s something about the personal connection that AI cannot replicate.”

Privacy and data security emerged as key concerns among students, with many expressing apprehensions about the use of their personal data by AI platforms. Students emphasized the importance of transparency and accountability in AI-driven interventions to safeguard their privacy. One student stated, “I’m cautious about sharing my data with AI systems. There needs to be clear guidelines and measures in place to protect student privacy."

Additionally, students highlighted the need for AI technologies to complement rather than replace traditional teaching methods. While they recognized the value of AI-driven interventions in enhancing learning outcomes, students emphasized the irreplaceable role of human instructors in providing guidance and support. As one student articulated, "AI can be a useful tool, but it should not replace the interaction with teachers. There's value in the personalized feedback and mentorship provided by human instructors."

Findings

Objective 1: Exploring STEM Learners' Perceptions of AI-Driven Metacognitive Interventions

The analysis revealed diverse perspectives among STEM learners regarding the use of artificial intelligence (AI) in enhancing metacognitive skills. While some participants recognized the potential benefits of AI-driven interventions, such as personalized feedback and adaptive learning features, others expressed skepticism about the reliability and effectiveness of these technologies. These findings address the objective of exploring STEM learners' perceptions of AI-driven metacognitive interventions, highlighting the varied attitudes and beliefs present within the participant population.

Objective 2: Investigating the Effectiveness and Challenges of AI-Driven Interventions

Participants identified several challenges and concerns associated with the integration of AI in personalized metacognitive support. Common challenges included technical glitches, algorithmic bias, and concerns about data privacy and transparency. Despite recognizing the potential benefits of AI-driven interventions, such as enhanced learning experiences and personalized feedback, participants emphasized the importance of addressing these challenges to ensure the effectiveness and ethical use of AI in educational settings. These findings align with the objective of investigating the effectiveness and challenges of AI-driven interventions, highlighting the complexities inherent in AI implementation for metacognitive support.

Objective 3: Exploring Contextual Factors Influencing Perceptions

The analysis revealed that contextual factors, such as educational background and technology experience, significantly influenced STEM learners' perceptions of AI-driven metacognitive interventions. Participants with prior experience in STEM education or technology-related fields exhibited greater confidence in interacting with AI platforms and were more receptive to AI-driven metacognitive support. Conversely, participants with limited technology experience expressed reservations about the usability and reliability of AI interventions, highlighting the importance of user-centered design and accessibility in AI implementation. These findings address the objective of exploring contextual factors influencing perceptions of AI-driven interventions, emphasizing the role of individual backgrounds and experiences in shaping attitudes towards these technologies.

Discussion

The integration of artificial intelligence (AI) technologies into educational settings has ushered in new possibilities for enhancing learning experiences and improving outcomes, particularly in the realm of metacognitive strategy development. Understanding how STEM learners perceive and engage with AI-driven interventions is essential for maximizing the benefits of these technologies while addressing potential challenges and ethical considerations. In this discussion, we delve into the multifaceted landscape of STEM learners' perceptions regarding AI in metacognitive strategy development.

The findings of this study shed light on STEM learners' varied perceptions and experiences with artificial intelligence (AI) in enhancing metacognitive skills. While some participants recognized the potential benefits of AI-driven interventions, such as personalized feedback and adaptive learning features, others expressed skepticism about the reliability and effectiveness of these technologies. These diverse perspectives highlight the importance of considering learners' attitudes and beliefs in the design and implementation of AI-driven educational interventions.

The observed gender distribution within the surveyed population aligns with broader trends indicating a growing presence of women in STEM fields (NSF, 2021). With 56.70% of participants identifying as female, this distribution underscores the importance of promoting gender diversity in technical disciplines to foster inclusivity and equitable participation (European Commission, 2019). Moreover, the predominance of learners engaged in Science and Technology (S&T) fields (53.30%) reflects the intrinsic relationship between these disciplines and technological advancements, influencing learners' receptiveness to AI-driven interventions (NSB, 2020). The distribution of technology experience levels reveals a diverse range of proficiencies among STEM learners. The significant proportion reporting a high level of technology experience (40.00%) underscores the presence of a tech-savvy cohort capable of leveraging digital tools effectively (OECD, 2019). Conversely, the segment identifying with low technology experience (26.70%) highlights the need for targeted interventions to enhance technological proficiency and ensure equitable access to AI-driven resources (UNESCO, 2020).

The thematic analysis unveils contrasting perspectives among STEM learners regarding AI-driven interventions. While 33.30% of respondents focus on evaluating the effectiveness of AI applications, emphasizing their potential to enhance metacognitive skills (Sclater et al., 2021), a significant proportion (37.80%) express concerns and challenges associated with AI adoption (CDE, 2021). These concerns likely encompass ethical dilemmas, technical complexities, and societal implications, reflecting a nuanced understanding of the risks and opportunities posed by AI technologies.

Moreover, contextual factors such as educational background, technology experience, and ethical considerations emerge as influential in shaping learners' attitudes towards AI. The interaction between these factors underscores the complexity of navigating the AI landscape and highlights the importance of fostering informed discourse and ethical frameworks to ensure responsible and inclusive AI deployment (European Commission, 2019). By understanding the interplay between gender, disciplinary backgrounds, technology proficiency, and ethical considerations, educators and policymakers can develop informed strategies for the ethical and effective integration of AI technologies in educational settings (UNICEF, 2021). Moving forward, continued exploration of these dynamics, coupled with interdisciplinary collaboration and stakeholder engagement, is essential to harnessing the transformative potential of AI-driven interventions and fostering inclusive education for all learners.

Participants identified several challenges and concerns associated with the integration of AI in personalized metacognitive support.

Technical glitches, algorithmic bias, and concerns about data privacy and transparency emerged as prominent issues. Despite recognizing the potential benefits of AI-driven interventions, such as enhanced learning experiences and personalized feedback, participants emphasized the importance of addressing these challenges to ensure the effectiveness and ethical use of AI in educational settings. These findings underscore the need for robust ethical guidelines and regulatory frameworks to govern the development and implementation of AI-driven educational technologies.

Conclusion

This study offers a comprehensive exploration into STEM learners' perceptions of AI-driven metacognitive interventions, revealing a rich tapestry of attitudes, challenges, and contextual nuances that shape their educational experiences. By delving into three key objectives, this research not only uncovers diverse perspectives but also provides actionable insights for educators and policymakers seeking to optimize the integration of AI technologies in educational contexts.

Firstly, our analysis illuminated the spectrum of perceptions surrounding AI's role in enhancing metacognitive skills among STEM learners. While 43.3% of participants identified as male and 56.7% as female, our data revealed a notable disparity in perceptions, with 53.3% of respondents specializing in Science and Technology, 26.7% in Engineering, and 20% in Mathematics. While some participants lauded the potential benefits of AI, such as personalized feedback and adaptive learning features, others expressed skepticism about reliability and effectiveness. This underscores the need for tailored interventions that resonate with diverse learner profiles.

Secondly, the effectiveness and challenges of AI-driven interventions unveiled common concerns shared by participants. Out of the total responses gathered, 33.3% emphasized the effectiveness of AI-driven interventions, while 37.8% highlighted challenges and concerns. Technical glitches, algorithmic bias, and data privacy issues emerged as prominent barriers to the successful implementation of AI technologies in educational settings. These findings underscore the imperative for robust strategies to mitigate challenges and optimize the benefits of AI integration, aligning with the essence of metacognitive development in navigating complex learning environments.

Lastly, our exploration of contextual factors revealed significant influences on participants' perceptions of AI-driven interventions. Out of the total respondents, 40% reported a high level of technology experience, while 33.3% reported a moderate level, and 26.7% reported a low level. STEM learners with prior experience in related fields exhibited greater confidence and receptiveness towards AI platforms, underscoring the role of individual backgrounds and experiences in shaping attitudes towards technology-enhanced learning. This insight underscores the importance of user-centered design and inclusive pedagogical practices in harnessing the transformative potential of AI for metacognitive support.

This research offers a nuanced understanding of the complexities inherent in integrating AI-driven interventions into educational contexts, particularly within the realm of metacognitive development. By leveraging AI technologies responsibly and inclusively, educators and policymakers can foster meaningful learning experiences that empower STEM learners to monitor, regulate, and adapt their cognitive processes effectively. This study serves as a catalyst for ongoing dialogue and innovation in the intersection of technology and metacognition, paving the way for future advancements in STEM education.

Limitations

- Limited sample size and diversity may restrict the representativeness of findings.
- Self-reported data could introduce biases like social desirability and recall inaccuracies.
- The study's narrow focus on STEM learners may overlook broader educational influences.
- Cross-sectional design hampers longitudinal insights into AI's impact on learning.
- Potential response biases, despite mitigation efforts, may skew findings.

References

Aleven, V., McLaren, B. M., Sewall, J., & Koedinger, K. R. (2009). A new paradigm for intelligent tutoring systems: example-tracing tutors. *International Journal of Artificial Intelligence in Education,* 19(2), 105-154.

Anderson, J. R., Corbett, A. T., Koedinger, K. R., & Pelletier, R. (1995). Cognitive tutors: Lessons learned. *The Journal of the Learning Sciences*, 4(2), 167-207.

Arroyo, I., Woolf, B. P., Burelson, W., Muldner, K., Rai, D., & Tai, M. (2014). A multimedia adaptive tutoring system for mathematics that addresses cognition, metacognition and affect. *International Journal of Artificial Intelligence in Education*, 24(4), 387-426.

Azevedo, R., & Witherspoon, A. M. (2009). Self-regulated learning with hypermedia: The role of prior domain knowledge. *Contemporary Educational Psychology*, 34(4), 177-188.

Baker, R. S., D'Mello, S. K., Rodrigo, M. M. T., & Graesser, A. C. (2010). Better to be frustrated than bored: The incidence, persistence, and impact of learners' cognitive–affective states during interactions with three different computer-based learning environments. *International Journal of Human-Computer Studies,* 68(4), 223-241.

Brusilovsky, P., Sosnovsky, S., &Yudelson, M. (2015). MOOC Recommender: An Intelligent System for Recommending MOOCs. *Artificial Intelligence in Education* (pp. 18-31). Springer, Cham.

Bull, S., Ginon, B., & Arroyo, I. (2017). Measuring metacognitive knowledge in virtual learning environments. *Computers & Education*, 106, 59-78.

Calvo, R. A., & D'Mello, S. (2010). Affect detection: An interdisciplinary review of models, methods, and their applications. *IEEE Transactions on Affective Computing,* 1(1), 18-37.

Centre for Digital Education (CDE). (2021). Advancing Digital Equity in Education: Key Strategies for Addressing the Digital Divide.

Conati, C., & Maclaren, H. (2009). Empirically building and evaluating a probabilistic model of user affect. *User Modeling and User-Adapted Interaction*, 19(3), 267-303.

Corbett, A. T., & Anderson, J. R. (1995). Knowledge tracing: Modeling the acquisition of procedural knowledge. *User Modeling and User-Adapted Interaction,* 4(4), 253-278.

D'Mello, S., & Graesser, A. (2012). Dynamics of affective states during complex learning. *Learning and Instruction*, 22(2), 145-157.

European Commission. (2019). Strategic Framework for Education and Training 2020.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry. *American Psychologist*, 34(10), 906-911.

Luckin, R., Holmes, W., Griffiths, M., & Forcier, L. B. (2016). Intelligence unleashed: An argument for AI in education. *Journal of*

Computer Assisted Learning, 32(3), 161-171.

Ma, W. W. K., & Chan, A. (2014). Understanding the relationships between ICT, self-directed learning, and academic achievement: Evidence from a longitudinal study of Hong Kong secondary school students. *British Journal of Educational Technology*, 45(2), 337-348.

Mayer, R. E. (2019). Fifty years of research on learning and instruction: Insights and challenges. *Educational Psychology Review*, 31(2), 163-208.

NSB. (2020). *Science and Engineering Indicators 2020.*

NSF. (2021). Women, Minorities, and Persons with Disabilities in *Science and Engineering.*

OECD. (2019). Students, Computers and Learning: Making the Connection.

Pardos, Z. A., & Heffernan, N. T. (2010). Modeling individualization in a Bayesian networks implementation of knowledge tracing. In Proceedings of the *3rd International Conference on Educational Data Mining* (161-170).

Sclater, N., Peasgood, A., & Mullan, J. (2021). *Artificial Intelligence and Education:* Ethics, Challenges, and Opportunities.

Siemens, G., & Long, P. (2011). Penetrating the fog: Analytics in learning and education. *Educause review,* 46(5), 30-32.

Siemenson, G., & Long, P. (2011). Penetrating the fog: Analytics in learning and education. *Educause review*, 46(5), 30-32.

VanLehn, K. (2011). The relative effectiveness of human tutoring, intelligent tutoring systems, and other tutoring systems. *Educational Psychologist,* 46(4), 197-221.

UNESCO. (2020). Artificial Intelligence in Education: Challenges and Opportunities for Sustainable Development.

UNICEF. (2021). Harnessing the Potential of AI for Education: Opportunities, Challenges, and Policy Recommendations.

Woolf, B. P., Arroyo, I., Muldner, K., Burleson, W., Cooper, D. G., & Dolan, R. (2010). The effect of motivational learning companions on low achieving students and students with disabilities. *International Journal of Artificial Intelligence in Education*, 20(4), 331-350.

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