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Integrating Generative AI in Metacognitive Learning Environment: A Systematic Literature Review

Soumyabrata Mahapatra
Doctoral Research Scholar, Department of Education, Ravenshaw University
Email Id: smbrt994@gmail.com, ORCID ID: 0000-0001-7699-9162
&
Prof. Sarat Kumar Rout
Professor of Education, Department of Education, Ravenshaw University
Email: saratrout2007@rediffmail.com, ORCID ID: 0009-0000-6478-3807
&
Panchali Kaushik
Doctoral Research Scholar, Tezpur University
Email: panchalikaushik05@gmail.com, ORCID ID: 0009-0000-1217-7741
&
Prof. Sudarshan Mishra
Head & Dean, School of Education, Ravenshaw University
Email: hodeducation@ravenshawuniversity.ac.in, ORCID ID: 0000-0002-7198-8955
&
Bikkshyatsib Sardar
Doctoral Research Scholar, Department of Education, Ravenshaw University
Mail ID: sbikshyatsib1@gmail.com, ORCID:0009-0007-2626-904X

Abstract

Educational institutions can expect generative artificial intelligence (AI) systems to provide many opportunities to change how students learn. Generative AI will transform how we view and think about learning by altering how we develop self-regulated and metacognitive engagement while placing adaptive learning as the primary focus of instruction. The rapid advancement of generative AI-based education technology allows educators to provide personalized instruction to a large number of students instantaneously while encouraging many of the types of critical thinking emphasized by recent reform efforts in learner-centered education such as India's National Education Policy (NEP) 2020. We developed and utilized a systematic review methodology to assess and synthesize the evidence from 17 studies retrieved from our research database that investigated the potential roles that generative AI systems may play in facilitating reflective learning and holistic educational outcomes and identified a number of barriers to the effective application of AI in educational settings. Results from our systematic review confirmed that generative AI-based learning environments enhance learners' metacognitive skills, creativity, and problem-solving ability through adaptive learning and intelligent tutoring systems. Qualitative studies on generative AI-based educational practices outnumber quantitative studies, with little evidence of diversity in mixed-method designs. There are several additional barriers to the use of natural language processing (NLP) techniques to provide support to learners in developing metacognitive abilities, including ethical concerns & algorithmic bias, and a lack of adequate infrastructure and teacher readiness. Developing a meaningful digital infrastructure that is scalable and usable in most educational settings will require the development of teachers who are knowledgeable and able to use AI, and the establishment of appropriate ethical governance processes for generative AI systems. This study demonstrated that generative AI provides opportunities to enhance the quality of student-centric learning experiences, but generative AI must be implemented in a fair and equitable manner. Future studies should specifically examine the long-term potential effects of generative AI on cognitive growth, particularly in regards to the ways that generative AI will impact the creation and maintenance of reflective learning environments.

Keywords: *Adaptive & Reflective Technologies, Generative AI, Holistic Educational Outcomes, Metacognitive Learning Environments.*

Introduction

The application of Artificial Intelligence (AI) in education could revolutionize the way students relate to information, as part and parcel of the overall transformation of the Fourth Industrial Revolution (Yogesh et al., 2023). Of the many aspects of the impact of AI on education, the metacognitive aspect of learners' ability to plan, monitor, and evaluate their own learning has attracted special academic interest because of the potential of changing the learning path in a significant way (Flavell, 1979). It closely relates to structured planning, environment management, cognitive monitoring, self-regulated learning (Callawaya et al., 2022). Metacognitive practices help

learners develop adaptive competence, the capacity to navigate dynamic learning contexts fit for an information-rich digital age that changes rapidly, and that requires individuals to self-correct continuously (Khotimah et al., 2024). AI and metacognition convergence therefore offers scope to design not only adaptive and personalized learning systems, but also emotional resilience and social development (Elsayary, 2024). With the emergence of new technologies, the combination of generative artificial intelligence (AI) and metacognition creates a pathway for intelligent learning environments that support a wide variety of growth goals while contributing to the overall advancement of education (Caro et al., 2014). Generative AI is at the forefront of the development of AI technology and has the potential to inspire creativity, support critical judgment and empower learners to establish their learning paths (Wong & Viberg, 2024). In contrast to traditional hierarchies in education, such platforms can enable students to share in the construction of information rather than serve only as passive receivers of information (Tripathi et al., 2024). Generative AI systems can help not only meet the pedagogical needs of today, but also those set forth in the National Education Policy (NEP) of India 2020 which establishes expectations for creating skills-based, student-centered systems (Wang et al., 2022; Tripathi et al., 2024). The foundational process of metacognition allows learners to organize, monitor, and evaluate their approaches to learning (Flavell, 1979). Increased access to the metacognitive processes will help the student meet challenging learning experiences with the psychological discipline, emotional resilience, and analytical capabilities needed to understand the area being studied (Sidra & Mason, 2024). AI-enabled solutions such as generative and adaptive tutors provide learners with the opportunity to think about or reflect on their learning strategies and allow students to explore various approaches to achieving a mastery of the content (Kabudi et al., 2021). Students will be better able to understand the limits of their current knowledge through the use of personalized systems and will have an increased ability to engage in analysis throughout their lives (Zhao & Ma, 2021). NEP 2020 emphasizes the critical role of technology in Closing the Gap of Inclusion, Experience and Holistic Education (Olaf et al., 2019; Tripathi et al., 2024) by recommending the development of a Foundational Literacy and Numeracy system and creating a framework for Personalized Learning. NEP considers the potential for AI to act as an equitable partner in the advancement of educational processes by providing personalized assistance and adapting to the unique needs of each learner (Olaf et al., 2019; Tripathi et al., 2024). Generative AI may assist in creating flexible, classroom-like experiences, not only enhancing the student socially and technologically, but also assisting in not only learning and testing to achieve success but also growing as problem solvers in this new world (Vartiainen et al., 2020). While the opportunities offered using generative AI are unlimited, so too are the potential risks associated with ethical issues, algorithmic bias, cultural understanding, teacher preparation, and readiness (Johnson, 2022). The warnings are a reminder of the importance of a responsible approach in implementing effective pedagogies (Kabudi et al., 2021) and not to make assumptions about the meaning of integrating learning strategies for us. The NEP 2020 includes recommendations for building Educators' Capacity for responsible Action, Ethical Adoption and Continuous Professional Development (Yogesh et al., 2023). The studies referenced aim to provide insight into how AI technology (specifically Generative AI) may be an effective instrument for creating metacognitive qualities within learning models that are inquisitive in nature (Khotimah et al., 2024), allowing all learners to engage with Reflection and Without risk within or outside of the AI method. The study also advocates discussing the potential of generative AI towards holistic aims and may discuss sustainable growth conforms technological, organizational, and ethical (Olaf et al., 2019) course of generative AI innovation towards a digital inclusive ecosystem to align with the NEP 2020 (Wang et al., 2024).

Through this comprehensive systematic analysis, the study answers the following key research questions:

- **i.** What role does AI-driven technology play in enhancing reflective and adaptive learning?
- **ii.** How could Generative AI help enrich holistic educational outcomes?
- **iii.** What challenges exist in implementing Generative AI into education, and how could they be dealt with?

Methodology

In carrying out synthesis review methodology, the study aimed to note the place of Generative AI in education especially for metacognitive learning environments. In short, the study followed mind mapping method by Arksey & O'Malley (2005) which includes five stages: (1) clear articulation of a research question; (2) identifying relevant studies; (3) study selection, (4) charting data; and, only then, (5) finally, data collation and summary and reporting, as necessary for scoping review. The working method was determined according to the PRISMA (Tricco et al. 2018).

Study Identification

Three databases were comprehensively searched: ScienceDirect, ResearchGate, and Google Scholar, using keywords related to Generative AI, metacognition, adaptive learning, and educational outcomes. Journal articles, conference proceedings, and grey literature published to date were included in the results.

Study Selection

The selection of studies includes a total of seventeen studies pertaining to the incorporation of Generative AI into education. Titles will first screen these studies, followed by an abstract and full-text review, for their relevance to the research questions.

Data Charting

Data extraction identified the following items pertinent to the general aspect of study: design, the role of generative AI, metacognitive and adaptive-learning pedals, and other heads dealing with AI integration difficulties. A standard form was established to collect data points consistently.

Data Summarization and Reporting

The results were synthesized in term of the themes;

i. Conceptual framework for AI integration in Education.
ii. Impact on reflective and adaptive learning.
iii. Potential improvements in holistic educational outcomes.
iv. Challenges in implementation and strategies for overcoming them.

Data Management

EndNote and Rayyan were used to track references and for data extraction, to help maintain a "coherent approach to the review that establishes an order to the data collection". This systematic review yielded insights into the use of Generative AI in improving educational outcomes and associate meta-cognitive learning, and explore the positive and negative implications of AI on traditional pedagogy.

Table 1. Databases of review and keywords

Database	Key words
Science Direct	"Generative Artificial Intelligence" OR "Artificial Intelligence" OR "Reflective & Adaptive Educational Technology" AND "Metacognition" OR "Self- regulated Learning" OR "Cognitive Regulation" OR "Cognitive Controlling" AND " Education" OR "Holistic Learning environment" OR "learning Outcomes"
Google scholar	"Generative Artificial Intelligence" OR "Artificial Intelligence" OR "Reflective & Adaptive Educational Technology" AND "Metacognition" OR "Self- regulated Learning" OR "Cognitive Regulation" OR "Cognitive Controlling" AND " Education" OR "Holistic Learning environment" OR "learning Outcomes"
Research Gate	"Generative Artificial Intelligence" OR "Artificial Intelligence" OR "Reflective & Adaptive Educational Technology" AND "Metacognition" OR "Self- regulated Learning" OR "Cognitive Regulation" OR "Cognitive Controlling" AND "Education" OR "Holistic Learning environment" OR "learning Outcomes"

Literature Screening

SRA software was used to eliminate duplicate studies; after which we screened the remaining literature for congruency. Those who made the cut were selected for reading in full; others rejected based on previously established criteria. All disputes (and we had many) were resolved with similar expert assistance. Study selection is summarized in the PRISMA diagram (Figure 1).

Inclusion and Exclusion Criteria

Inclusion and exclusion criteria reduce bias, promotes consistency, and guarantees credibility so meaningful conclusions can be drawn from the results.

Search Strategy

The search strategy for systematic literature identification was adopted based on the guidelines by Gasparyan et al. (2011). The databases were searched using the strategy included in Table 1: Science Direct, ResearchGate, and Google Scholar. The search was limited to full-text articles written in English published from 2019 to 2024.

Table 2: Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
English language	Other than English language
Addressing research questions	Not addressing research question
Full article with abstract	Unpublished Documents
Addressing target population	Not addressing target population
Studies from Last 06 years	Not come under time frame

PRISMA Diagram

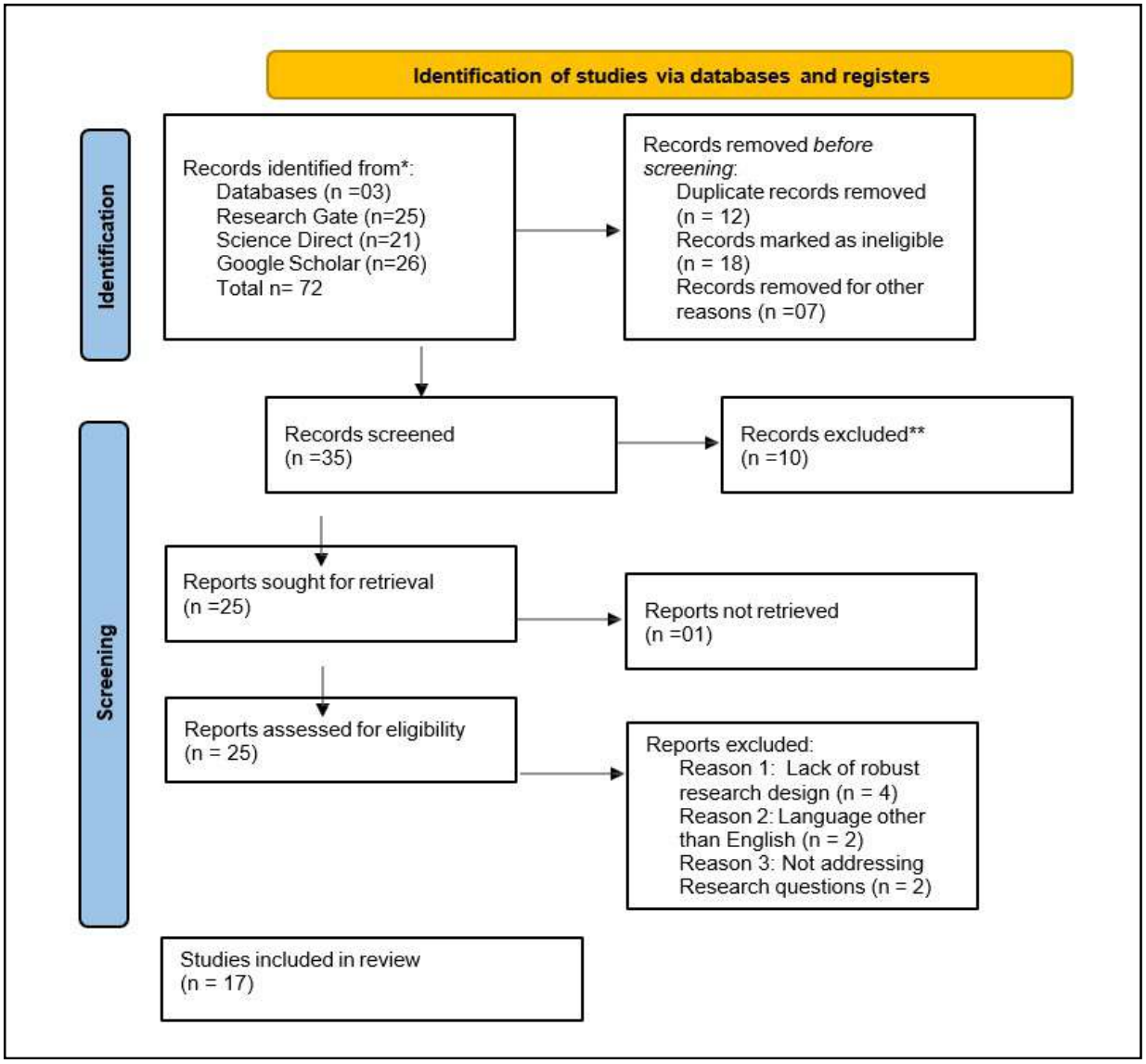


Table 3: Key findings of the selected studies

Study ID	Author (Year)	Methodology	Key Findings
MAI-1	Kabudi et al. (2021)	Systematic Review	The study reviewed 147 articles on AI-enabled adaptive learning systems, highlighting the benefits of personalized content delivery and real-time feedback. However, adoption is limited due to technical and organizational challenges, suggesting the need for scalable solutions.
MAI-2	Callaway et al. (2022)	Mixed Methods	An AI-driven intelligent tutor system was shown to improve decision-making by teaching optimal planning strategies, enhancing participants' ability to make far-sighted decisions.
MAI-3	Wong & Viberg (2024)	Quantitative	Generative AI (GenAI) supports self-regulated learning (SRL) by providing personalized feedback and peer-level support, fostering critical thinking. However, human oversight is essential to balance AI's role in education.
MAI-4	Khotimah et al. (2024)	Quantitative	A meta-learning approach enhanced metacognitive and creativity skills among undergraduate students, leading to significant improvements in self-awareness, self-regulation, and reflective thinking.

MAI-5	Caro et al. (2014)	Quantitative	The study developed MISM 1.1, a metamodel for integrating metacognition into AI systems, improving adaptability by incorporating self-regulation, metamemory, and meta-comprehension.
MAI-6	Elsayary (2024)	Qualitative	GenAI enhances metacognitive regulation and technological proficiency in active learning environments, promoting critical thinking and dynamic educational experiences.
MAI-7	Vartiainen et al. (2020)	Quantitative	AI-based teachable machines improved metacognitive awareness and critical thinking in children aged 3–8, helping them understand learning strategies like scaffolding.
MAI-8	Jackson (2020)	Qualitative	AI's metacognitive capabilities can contribute to reasoning in scientific domains, advancing metascience and supporting interdisciplinary research.
MAI-9	Sidra & Mason (2024)	Qualitative	The study emphasizes the importance of metacognitive skills in human-AI interactions, noting that AI systems need improved metacognitive capabilities to mitigate biases and improve decision-making.
MAI-10	Wang et al. (2022)	Quantitative	The development of an AI Literacy Scale measures competence in AI technologies across awareness, use, evaluation, and ethics, providing a framework for assessing the impact of AI on learning and metacognition.
MAI-11	Zhao & Ma (2021)	Quantitative	A virtual reality system enhanced metacognitive awareness and performance in elevator pitch training, demonstrating the potential of VR and AI in adaptive learning.
MAI-12	Johnson (2022)	Qualitative	Embedding metacognition into AI systems can boost their self-awareness and safety, suggesting the incorporation of such features for the better adaptability and moral functioning of AI in education.
MAI-13	Tripathi et al. (2024)	Mixed Methods	The AI tool enhanced students' metacognitive awareness and academic performance. However, challenges were identified in the use of the tool and needed improvement in its design and functionality.
MAI-14	Olaf et al. (2019)	Mixed Methods	Developing tools through the lens of a higher education AI review furthered profiling, assessments, adaptive systems, and tutoring. The review cited a lack of stronger pedagogical and ethical frameworks to inform the deployment of AI by schools.
MAI-15	Yogesh et al. (2023)	Qualitative	The study evaluated the manifold impact of research in AI on a myriad of areas such as healthcare, business, and education and drew attention to the ways in which AI could further assist in solving complex societal problems.
MAI-16	Callaway et al. (2024)	Systematic Review	The article proposes an AI strategy for optimizing human decision-making by teaching optimal planning strategies. The study demonstrates how an intelligent tutoring system, utilizing AI to discover the heuristic, significantly improves decision-making skills.
MAI-17	Wang et al. (2024)	Qualitative	This review paper provides a comprehensive overview of artificial intelligence (AI) applications in education, categorizing them into adaptive learning, personalized tutoring, intelligent assessment, and profiling and prediction. Through bibliometric analysis and content analysis of 2,223 articles, the review identifies predominant research topics, highlighting both the technological designs and educational impacts of AI.

Figure 2. Clustered bar diagram of types of research followed in selected studies

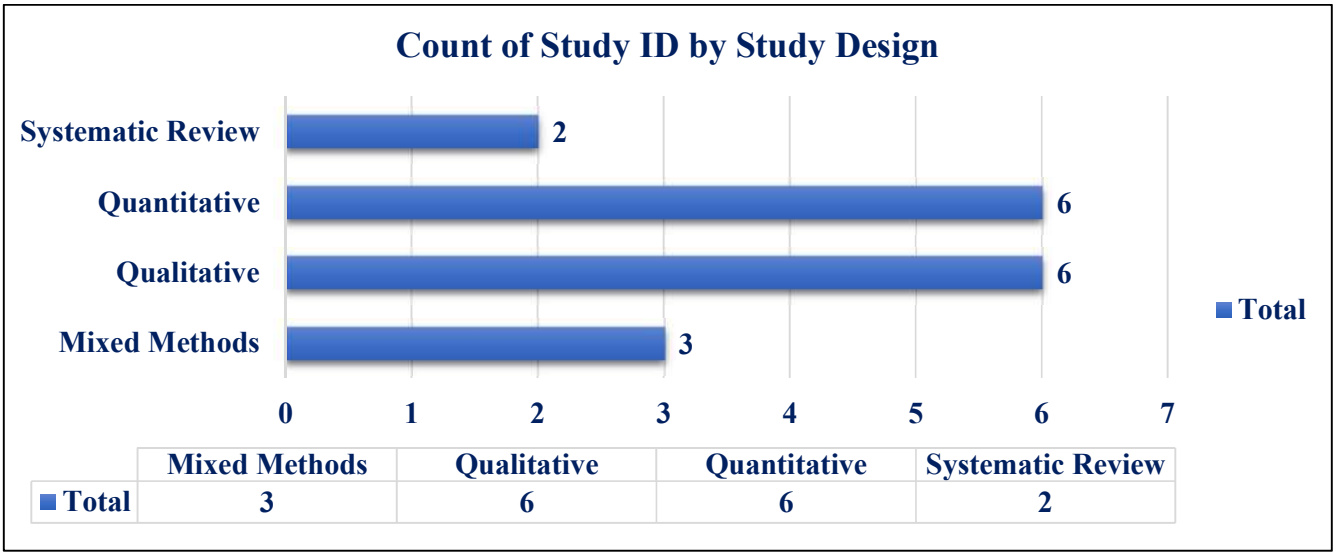
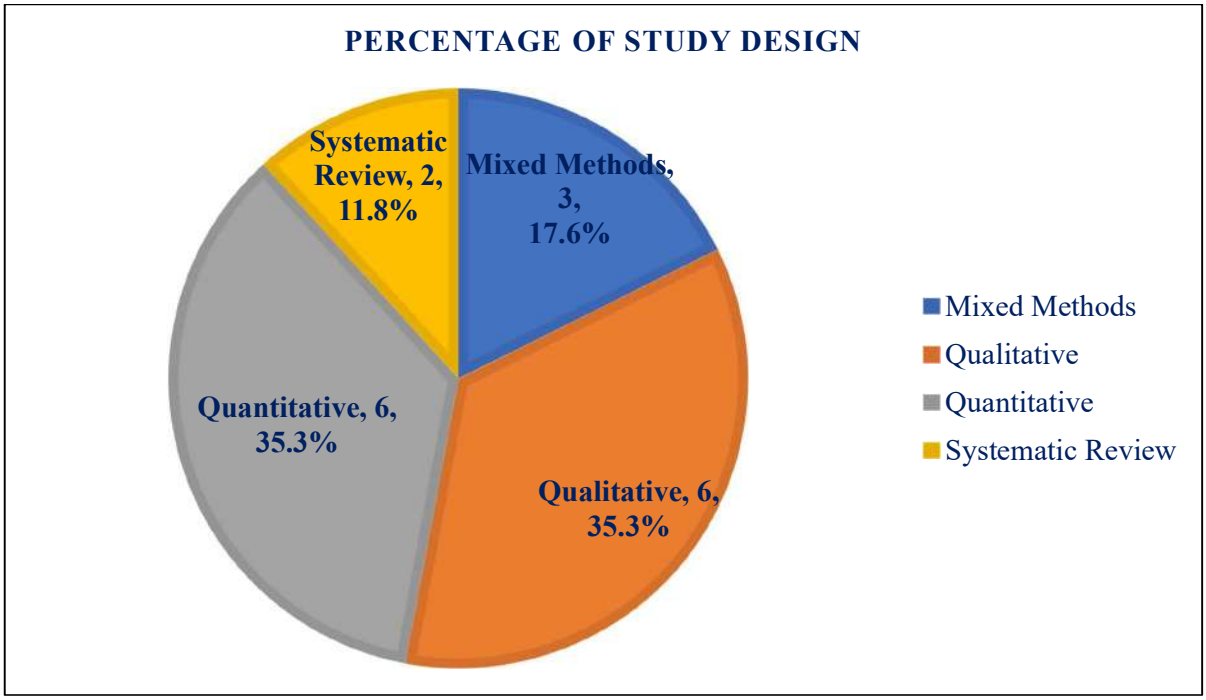


Figure 3. Pie-chart diagram of types of research with percentage followed in selected studies



The figure 2 and 3 respectively Clustered bar and pie chart diagram shows the distribution of methodologies used in research across the 17 studies. Of these studies, qualitative and quantitative research comprise the vast majority, each accounting for 35.3%. Mixed methods comprise 17.6% and systematic reviews comprise 11.8%. There appears to be a very strong leaning toward qualitative and quantitative studies, less frequently mixed methods, and systematic reviews. The details show qualitative research was largely for theoretical exploration and conceptual inquiries, while quantitative research relied upon empirical assessments of the usefulness of AI. This methodology has a good typical use, and systematic reviews synthesize literature. The picture reveals equal use of qualitative and quantitative research to investigate AI's role in education.

Research Questions Analysis

i. What role does AI-driven technology play in enhancing reflective and adaptive learning?

These systems allow, for example, the smart tutor system, learners to work on the materials in personalized ways that improve reflection and adaptation. Callawaya et al. (2022) have presented new empirical evidence supporting the use of AI to aid in making decisions based on optimal planning methods that result in reflective choices. Their research also supports the importance of reflective choice making within the context of the learning process. This represents a significant benefit of using AI to enhance educational outcomes. Additionally, Khotimah et al. (2024) found that the application of meta-learning enhances students' metacognitive skills, improves creativity, and aids in developing students' self-regulated learning. All of the above evidence illustrates how AI technology can support learners' ability to think about their thinking and regulate their own learning in a way that promotes reflective learning. The development and application of metacognitive awareness has been identified by Vartiainen et al. (2020) as a critical component of the calibration of learning strategies. AI systems facilitate learners' logical thinking; as such, many of the learning strategies that AI systems promote encourage children to develop metacognitive awareness and critical thinking skills in areas such as scaffolding. AI systems will offer more than just individualized content; they will provide support for developing students' understanding of how to learn.

ii. How could Generative AI help enrich holistic educational outcomes?

Generative artificial intelligence supports holistic educational outcomes via self-regulated learning (SRL) and the provision of personalized feedback (Wong & Viberg, 2024). The ability to adapt to one's own progression as well as that of peers will foster an important attribute of critical thinking and other self attributes that will ultimately lead to enhanced academic success on a holistic basis. Khotimah et al. (2024) elaborated that the results correspond with profound advancements in students' self-awareness, metacognition, fostering them into academic and developmentally significant creativity. Another author, Elsayary (2024) pointed out that GenAI fortifies metacognitive control with critical thinking abilities and technology within active learning communities. Using Wong & Viberg's ideas that search itself, encourages this will mean student handle maintain, and inculcate AI and intrinsic traits that are useful to productivity beyond school, facilitating critical and meaningful learning, Johnson (2022) provided on building into AI systems.to make more capable to AI systems, being conscious of themselves and being a safer and agile AI system for education. Exchanging the nodes of heath and capacity and herb with the best of the human instructor, this ties AI systems into the educational ecosystem to enhance holistic use.

iii. What challenges exist in implementing Generative AI into education, and how could they be dealt with?

Challenges do exist both from within the mechanics, or rather from without as well. As Kabudi et al. (2021) explored, although AI provided for them a path towards personalized learning and real-time feedback, but the propensity for resistance against AI establishment, or indeed hindrances to installation and infrastructure. Their restoration would have consisted of those large infrastructures for operations, as well as persistent upskill opportunities for faculty members. Wong and Viberg (2024) emphasized that any such upskilling and introducing Generative AI within the course, a human overseer in form of human "AI function as the intuition of the instructional determination" must be attained, and by virtue of that, bear critical and reflecting learning. Finally, Sidra and Mason (2024) might have begun asking about the "AI ecology with metacognition" and others to eradicate biases. However, Olaf et al. (2019) also laid emphasis on the inadequacy of the strong pedagogical and ethical framework they cited as necessary for the employment of an AI system into the school. Wang et al (2022) & Johnson (2022) has also stressed the need for the comprehensive frameworks to assess AI competence and ethical applications in education. Therefore, scalable infrastructure, professional development for faculty members and AI integration process should be prioritized to address these issues.

Results and Discussion

Considering the methodological stance of the 17 papers reviewed (Figures 2 and 3), qualitative (35.3%) and quantitative research (35.3%) was represented almost equally, while mixed methods (17.6%) and systematic reviews (11.8%) were less common. The qualitative studies mainly involved theoretical and conceptual explorations, while the quantitative studies were mainly used for establishing as an empirical verification of AI

in educational settings. The lower prevalence of mixed-means research demonstrates a lack of effort in generating a syncretic AI pedagogical impact; Kabudi et al. (2021) Callawaya et al. (2022).

AI-Driven Technology in Reflective and Adaptive Learning

GenAI promotes education by furthering self-regulated learning (SRL), creativity, and metacognitive engagement. Wong and Viberg (2024) noted that GenAI interfaces with individual learning patterns and thus promotes reflective and cognitive skills development for students. Elsayary (2024) found that, in addition to stimulating engagement, GenAI helps students foster such metacognitive regulation as well as a sense of technology literacy. Khotimah et al. (2024) provide evidence to support the idea that AI-assisted learning enhances self-awareness and student creativity. Johnson (2022) has determined Metacognition is responsible for developing AI models that are able to integrate adaptability and ethical consistency within educational systems. All these points at GenAI as enabling personalized learning and cognitive and reflective skills development for holistic education.

Generative AI and Holistic Educational Outcomes

Developing Holistic Educational Outcomes through Generative AI Generative AI supports Self-Regulated Learning (SRL), Creativity, & Metacognitive Engagement within Educational Systems. Wong & Viberg (2024) demonstrated the interface of Generative AI with student learning patterns promoting Reflection & Cognition Skills Development. Elsayary (2024) determined the ways in which Generative AI increases engagement and develops Metacognitive Regulation and Technology Literacy among Students. Khotimah et al. (2024) supported the view that AI-Assisted Learning is able to increase Self-Awareness and Student Creativity. Johnson (2022) pointed out that Metacognition is the reason for the development of AI Models which can produce Adaptability and Ethical Consistency in Education Systems. All these points at GenAI as enabling personalized learning and cognitive and reflective skills development for holistic education.

Challenges and Implementation Strategies for Generative AI in Education

Despite its potential, GenAI in education faces hurdles; technical, organizational as well as ethical ones. Infrastructure obstacles plus resistance to AI adoption become substantial barriers to the penetration of AI into educational settings (Kabudi et al., 2021). Educational institutions should also create a robustly specified digital infrastructures plus continuous learning for educators. Wong and Viberg (2024) found that it is necessary to oversee AI-augmented education practices to avoid overdependence on automated systems and to ensure that AI strengthens traditional pedagogies rather than supersedes them. One of the most pressing issues is ethical in nature, bias inheres in the AI decision-making process. Olaf et al. (2019) claim existing AI applications do not exhibit a robust enough ethical framework. Thus, regulatory guidelines for AI in education are necessary. Sayeed & Sidra & Mason (2024) have argued that AI must improve its metacognitive skills to reduce bias and improve fairness. Wang et al. (2022) and Johnson (2022) advocate for the timely intervention of systematic frameworks for use of responsible and ethical AI.

Conclusion

Gen-AI has the potential to transform how we educate in the future using self-regulated, personalized means of learning. Gen-AI can provide adaptive feedback and intelligent tutor systems for learners as well as supports for our own metacognitive processes. Furthermore, when we start to think of how the concepts taught in the NEP will lead to greater creativity, autonomy and critical thinking, Gen-AI has the potential to provide tools and resources to help our students develop these same traits.

However, there are still many ethical dilemmas and challenges to be overcome. If we are going to use Gen-AI and other intelligent systems to inform our teaching decisions, we must place clarity around ethical standards that support humanity's choices and the continued use of responsible practices for teaching and learning. Equitable access to technology is still a very important issue. We must invest in developing our institutional capacity by developing digital pedagogies, providing both tools and support (i.e., infrastructure, training of teachers) for working with Gen-AI to help students who have been historically underserved and to avoid the widening digital divide. The role of Gen-AI in educational reform must be cautiously and thoughtfully approached. Rather than making human pedagogy obsolete, Gen-AI should support, augment, and enhance human pedagogy. To create sustainable learning environments based on Gen-AI that promote access, equity and metacognitive growth, rigorous longitudinal studies are needed to understand the relationship between Gen-AI and learner cognitive development, self-regulation and learning results over time. Eventually, Gen-AI has the potential to create flexible, adaptive learning environments that are based on sound pedagogical practices and foster the development of deeper learning, personal engagement, and ethical innovation in education.

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