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From AI Adoption to Meaningful Learning: A Systematic Review of AI-Based Pedagogy, Student Engagement and Critical Thinking in Higher Education

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Abstract: *Artificial Intelligence (AI) has rapidly evolved from a specialized computational technology into an increasingly important component of higher education, influencing teaching, learning, assessment and academic support. Intelligent tutoring systems, adaptive learning platforms, learning analytics, automated feedback, conversational agents and generative AI are creating new possibilities for personalized and interactive learning. At the same time, the rapid integration of AI has raised important concerns regarding student engagement, critical thinking, academic independence, AI literacy, teacher competence, digital infrastructure and responsible use. Existing research provides evidence of considerable educational potential, but findings remain fragmented across AI technologies, pedagogical approaches, disciplines and learning outcomes. This review critically examines the emerging literature on AI-based pedagogy in higher education, with particular emphasis on its relationship with student engagement and critical thinking. It further investigates the roles of AI literacy, perceived usefulness, teacher competence, AI-related technological-pedagogical knowledge, digital infrastructure and institutional readiness in determining the effectiveness of AI-supported learning. The review is conceptually grounded in Artificial Intelligence in Education (AIED), the Technological Pedagogical Content Knowledge (TPACK) framework, AI literacy and technology-adoption perspectives. The conceptual focus is consistent with the original manuscript, which identified AI literacy, perceived usefulness and digital infrastructure as important antecedents of AI-based pedagogy and positioned student engagement and critical thinking as major educational outcomes. A structured literature-review methodology is adopted to identify, screen, organize and thematically synthesize relevant research, with particular attention to AI-enabled personalization, adaptive learning, intelligent tutoring, generative AI, student engagement, critical thinking, AI literacy and institutional readiness. The review distinguishes between technological interaction and meaningful cognitive engagement, recognizing that frequent AI use does not necessarily indicate deeper learning. Similarly, AI may support critical thinking when used for questioning, comparison, evaluation and reflection, but may weaken independent reasoning when students simply delegate cognitive tasks to AI. The review proposes an AI–Pedagogy–Engagement–Critical Thinking (AI-PECT) framework in which AI capabilities influence educational outcomes through pedagogical mediation and learner agency, while AI literacy, teacher competence, infrastructure, assessment design and ethical governance operate as important contextual conditions. The review argues that the educational value of AI depends less on the presence of AI technology itself and more on how deliberately, critically and responsibly it is integrated into teaching and learning. The findings provide a foundation for educators, institutions and policymakers seeking to move from simple AI adoption toward meaningful, human-centred and intellectually responsible learning.*

Keywords: Artificial Intelligence; Artificial Intelligence in Education; AI-Based Pedagogy; Generative AI; Student Engagement; Critical Thinking; AI Literacy; AI-TPACK; Higher Education; Digital Learning; Responsible AI.

I. INTRODUCTION

Artificial Intelligence (AI) has become an increasingly influential technology in higher education, transforming the ways in which teaching, learning, assessment and academic support are designed and delivered. Advances in machine learning, natural language processing, learning analytics and generative AI have expanded the role of AI from relatively specialized educational applications to technologies that can interact directly with students and educators. Intelligent tutoring systems, adaptive learning environments, automated assessment, recommendation systems, conversational agents and generative AI applications are increasingly being considered as components of contemporary higher education. The original manuscript similarly identifies intelligent tutoring systems, automated grading, adaptive learning platforms and generative AI as important applications of AI in educational settings.

The development of generative AI has accelerated this transformation. Unlike many earlier educational technologies that operated primarily within predefined instructional environments, generative AI can respond dynamically to natural-language queries and produce explanations, examples, questions, summaries, feedback and other forms of educational content. The emergence of systems such as ChatGPT has therefore changed the relationship between learners and educational technology. Students can now interact with AI as an information source, writing assistant, tutor, brainstorming partner and problem-solving aid (Dwivedi et al., 2023; Kasneci et al., 2023). This development has created new opportunities for individualized learning and academic support but has also intensified debates concerning reliability, academic integrity, student dependency, misinformation and the possible displacement of independent intellectual work.

Nevertheless, the relationship between AI and engagement is not necessarily linear. High levels of interaction with an AI system do not necessarily represent meaningful engagement. A student who repeatedly asks an AI system to generate answers may be technologically active while remaining cognitively passive. Conversely, a student who uses AI to compare competing explanations, identify weaknesses in an argument, test assumptions and formulate independent conclusions may demonstrate deeper cognitive engagement. This distinction is particularly important in higher education, where learning outcomes increasingly emphasize analysis, evaluation, problem-solving and other forms of higher-order thinking rather than simple information acquisition.

Generative AI creates a particular paradox in this respect. On one hand, students can use AI to obtain alternative explanations, generate counterarguments, identify weaknesses in their reasoning and explore unfamiliar concepts. On the other hand, AI can perform tasks such as summarization, explanation, writing and problem-solving that students might otherwise undertake themselves. If these capabilities result in excessive cognitive offloading, students may complete academic tasks more efficiently without developing equivalent levels of independent reasoning. The distinction between AI-assisted cognition and AI-substituted cognition is therefore central to understanding the educational implications of AI. In AI-assisted cognition, the learner remains responsible for analysis and judgement while AI provides support, feedback or alternative perspectives. In AI-substituted cognition, the learner delegates a substantial portion of intellectual work to the technology. The educational consequences of these two models are likely to differ considerably.

Another important issue concerns AI literacy. Effective AI use requires more than technical familiarity with a particular application. Students need to understand the basic principles underlying AI systems, recognize their limitations, evaluate AI-generated information, identify potential bias and misinformation, protect personal information and make appropriate ethical decisions (Long & Magerko, 2020). AI literacy is consequently becoming an important component of higher education rather than a specialized skill restricted to computer science. The original manuscript identifies AI literacy as one of the major factors associated with AI-based pedagogy and places it alongside perceived usefulness and digital infrastructure as an important antecedent of AI-supported educational practices.

The central argument of this review is that AI should not be considered an independent determinant of educational quality. Instead, its effects are shaped by pedagogical mediation, learner agency, teacher competence and institutional conditions. This perspective represents a conceptual development of the original manuscript. The original study proposed that AI literacy, perceived usefulness and digital infrastructure influence AI-based pedagogy, which in turn influences student engagement and critical thinking. The present review retains these central constructs but reframes them within a broader literature-synthesis model in which pedagogical mediation and learner agency serve as central mechanisms linking AI capabilities with meaningful learning outcomes.

II. OBJECTIVES

Accordingly, the review has six major objectives. First, it seeks to examine the evolution and major applications of AI in higher education. Second, it critically synthesizes evidence concerning the relationship between AI-based pedagogy and student engagement. Third, it examines the relationship between AI-supported learning and critical thinking. Fourth, it identifies the roles of AI literacy, teacher competence and AI-TPACK in meaningful AI integration. Fifth, it examines the institutional, technological, assessment and ethical conditions that facilitate or constrain effective AI adoption. Finally, it develops an integrated conceptual framework explaining the relationships among AI capabilities, pedagogical mediation, learner agency, student engagement and critical thinking.

III. METHODOLOGY

The present study adopts a systematic critical review design that combines a structured literature-identification process with thematic and conceptual synthesis. The purpose is not merely to catalogue publications concerning AI in higher education but to critically examine how different forms of AI interact with pedagogy, learner processes and educational outcomes. Particular attention is given to the relationship between AI-based pedagogy and the two major educational outcomes identified in the original manuscript, namely student engagement and critical thinking. A critical review approach is appropriate because the existing literature encompasses substantial variation in AI technologies, educational settings, research designs, learner populations and outcome measures. Rather than assuming that all AI applications have equivalent educational effects, the review examines differences in technological purpose, pedagogical implementation and learning context.

The literature search should be structured around combinations of keywords representing the major concepts of the review. The principal search terms include combinations of “artificial intelligence,” “generative AI,” “ChatGPT,” “large language models,” “higher education,” “university,” “college,” “AI-based pedagogy,” “teaching,” “learning,” “student engagement,” “critical thinking,” “learning outcomes,” “cognitive engagement” and “AI literacy.” Additional searches should address more specific combinations, including “generative AI AND higher education,” “ChatGPT AND higher education,” “AI literacy AND education,” “AI-TPACK AND teacher competence,” “artificial intelligence AND critical thinking,” “artificial intelligence AND student engagement,” “AI AND self-regulated learning,” “AI AND academic integrity” and “responsible AI AND higher education.” This broad search strategy is intended to capture both established Artificial Intelligence in Education research and the rapidly expanding literature on generative AI.

The recommended information sources for the final review include Scopus, Web of Science, ERIC, ScienceDirect, SpringerLink, IEEE Xplore and Google Scholar for supplementary citation tracking. Scopus and Web of Science should form the principal evidence base because they provide broad multidisciplinary coverage and allow systematic identification of peer-reviewed literature. Education-specific databases such as ERIC can supplement this evidence by identifying studies that may not be strongly represented in multidisciplinary databases, while ScienceDirect, SpringerLink and IEEE Xplore can strengthen coverage of educational technology and AI-related research. However, the uploaded manuscript does not document an actual database search, number of records retrieved or screening process. Therefore, these elements should be regarded as the proposed review protocol unless an actual search is subsequently conducted and the numbers are documented.

Studies should be included when they examine university, college or other higher-education learners or educators and address AI, generative AI, intelligent tutoring, adaptive learning, conversational AI or related AI systems within teaching, learning, assessment or academic-support contexts. Particular attention should be given to studies examining student engagement, critical thinking, learning outcomes, autonomy, cognition or related educational outcomes, as well as research addressing AI literacy, AI competence, TPACK or AI-TPACK, digital infrastructure, institutional readiness, professional development and responsible AI. Peer-reviewed journal articles, systematic reviews, meta-analyses and selected high-quality conference papers should be considered eligible when they provide sufficient methodological or conceptual information. The primary publication language should be English, with the principal publication period extending from 2019 to 2024 while allowing the inclusion of earlier foundational studies.

Studies should be excluded when they focus exclusively on AI algorithms without an educational application, concern primary or secondary education without transferable higher-education evidence, fail to address teaching, learning, assessment or educational outcomes, consist solely of unsupported opinion, duplicate another publication, lack sufficient methodological or conceptual information, or concern general workplace AI without a meaningful educational context. Technical AI studies should therefore not be included merely because they are highly cited; they should contribute directly to understanding AI-supported higher education.

The literature-selection process should follow a structured sequence consisting of identification, deduplication, title and abstract screening, and full-text assessment. During the identification stage, potentially relevant publications should be retrieved using the predefined search terms across the selected databases. Duplicate records should then be removed. Titles and abstracts should subsequently be screened against the inclusion and exclusion criteria, after which potentially relevant publications should be examined in full. The final selection process should be reported using a PRISMA 2020 flow diagram showing the number of records identified, screened, excluded and finally included. Because the original manuscript does not report an actual PRISMA-based search, the final numbers should only be inserted after the database search has been completed.

Because the included studies are expected to differ substantially in technologies, populations, research designs and outcome measures, the primary synthesis should be thematic rather than based solely on statistical aggregation. The literature should be organized around major themes including AI-enabled personalization, student engagement, critical thinking, generative AI, AI literacy and teacher competence, institutional and technological readiness, and ethics and academic integrity. This thematic organization will permit the review to identify areas of convergence, contradiction and uncertainty across the literature.

IV. EVIDENCE SYNTHESIS

The reviewed literature demonstrates that Artificial Intelligence (AI) is increasingly being incorporated into higher education through intelligent tutoring systems, adaptive learning platforms, learning analytics, automated feedback, conversational agents and, more recently, generative AI and large language models. Earlier research established the potential of AI to support personalized learning, intelligent instructional assistance and adaptive educational environments (Luckin et al., 2016; Holmes et al., 2019). Zawacki-Richter et al. (2019), through a systematic review of AI applications in higher education, demonstrated that AI research covers teaching, learning, assessment and institutional functions, while also highlighting the need for stronger consideration of pedagogical and educational dimensions. Long and Magerko (2020) subsequently emphasized AI literacy as an important educational competency, arguing that learners require not only technical familiarity with AI but also the ability to understand, evaluate and critically engage with AI systems. More recently, the rapid emergence of generative AI has substantially expanded the scope of AI-supported education. Kasneci et al. (2023) and Dwivedi et al. (2023) identified significant opportunities associated with large language models, including personalized assistance, feedback, explanation and content generation, while simultaneously emphasizing concerns relating to misinformation, bias, academic integrity, reliability and excessive dependence on AI. Thus, the literature has progressively moved from viewing AI primarily as an instructional support technology toward understanding AI as an interactive cognitive and pedagogical tool.

The evidence concerning student engagement indicates that AI can contribute to behavioural, emotional and cognitive dimensions of engagement, but its effects are not universally positive. Student engagement is generally conceptualized as a multidimensional construct involving behavioural participation, emotional involvement and cognitive investment in learning (Fredricks et al., 2004). AI-supported learning environments can increase opportunities for interaction by providing immediate feedback, personalized learning resources, adaptive tasks and continuous academic support. The original manuscript similarly identifies personalization, continuous feedback and dynamic learning resources as mechanisms through which AI may influence student engagement. Recent research provides further support for this conditional relationship. A systematic review of ChatGPT and student engagement reported evidence of both engagement and disengagement, indicating that interaction with generative AI cannot automatically be equated with meaningful learning engagement. A subsequent systematic review examining AI and teaching methods reported that pedagogical approaches play an important mediating role between AI technologies and student engagement. Similarly, a recent meta-analysis of ChatGPT-supported learning reported a medium overall effect on student engagement, suggesting that AI can produce measurable educational benefits while also indicating the need to consider differences in implementation and learning context.

The literature concerning critical thinking presents an even more complex picture. Critical thinking involves processes such as interpretation, analysis, evaluation, inference, explanation and reflective judgement (Facione, 2015). AI can potentially support these processes by generating alternative explanations, presenting different viewpoints, producing counterarguments, assisting with complex problem-solving and providing feedback. The original manuscript similarly proposes that AI-supported learning environments can expose students to complex problem-solving and data-driven learning activities that may support analytical reasoning and inquiry-based learning. Recent reviews of generative AI and critical thinking have identified potential benefits associated with reflective reasoning, self-regulation, iterative dialogue, argument evaluation and problem-solving, particularly when students are required to critically examine AI-generated material rather than simply reproduce it. However, the literature also identifies a significant risk of cognitive offloading. When students delegate analysis, evaluation or problem-solving to AI, the technology may complete the cognitive task rather than support the development of the student's own reasoning abilities. Therefore, AI should not be considered inherently beneficial or harmful to critical thinking; its effects depend on the design of the learning activity and the degree of intellectual responsibility retained by the learner.

The evidence also highlights the importance of AI literacy. AI literacy involves understanding the basic principles and capabilities of AI, recognizing its limitations, evaluating its outputs and using AI responsibly (Long & Magerko, 2020). In higher education, AI literacy becomes particularly important because students increasingly encounter AI-generated information in academic, professional and everyday contexts. Students with stronger AI literacy may be better positioned to identify inaccurate information, recognize bias, formulate effective prompts, verify AI-generated claims and distinguish between useful assistance and inappropriate cognitive substitution. The original manuscript positions AI literacy as one of the important antecedents of AI-based pedagogy, together with perceived usefulness and digital infrastructure. The review therefore treats AI literacy not simply as a technical skill but as a component of critical digital competence that influences the quality and responsibility of AI-supported learning.

The literature also reveals several potential negative pathways associated with AI-supported learning. AI may reduce cognitive effort when students delegate academic tasks to automated systems, encourage passive acceptance of AI-generated information, increase dependency on technology and create uncertainty regarding authorship and academic responsibility. Generative AI can also produce inaccurate or fabricated information, commonly referred to as hallucinations, and can reproduce biases present in training data or generated responses. These concerns are particularly important in higher education because students are expected to develop independent judgement and disciplinary expertise. The challenge is therefore to design educational environments in which students learn *with AI without allowing AI to replace learning*.

Overall, the evidence suggests that the educational effects of AI are *conditional rather than automatic*. AI technologies provide capabilities, but pedagogy determines how those capabilities are translated into learning experiences. Student engagement depends on the quality of interaction and learner participation rather than simply the amount of technological activity. Critical thinking depends on whether AI encourages evaluation, reflection and independent judgement rather than replacing these processes. AI literacy determines whether students can use and evaluate AI responsibly, while teacher competence determines whether AI is embedded within appropriate pedagogical strategies. Institutional infrastructure and governance further determine whether AI-supported learning can be implemented equitably and responsibly. These findings support the conceptual direction of the original manuscript, which connects AI literacy, perceived usefulness and digital infrastructure with AI-based pedagogy and subsequently with student engagement and critical thinking.

V. PRISMA-BASED LITERATURE SELECTION FRAMEWORK

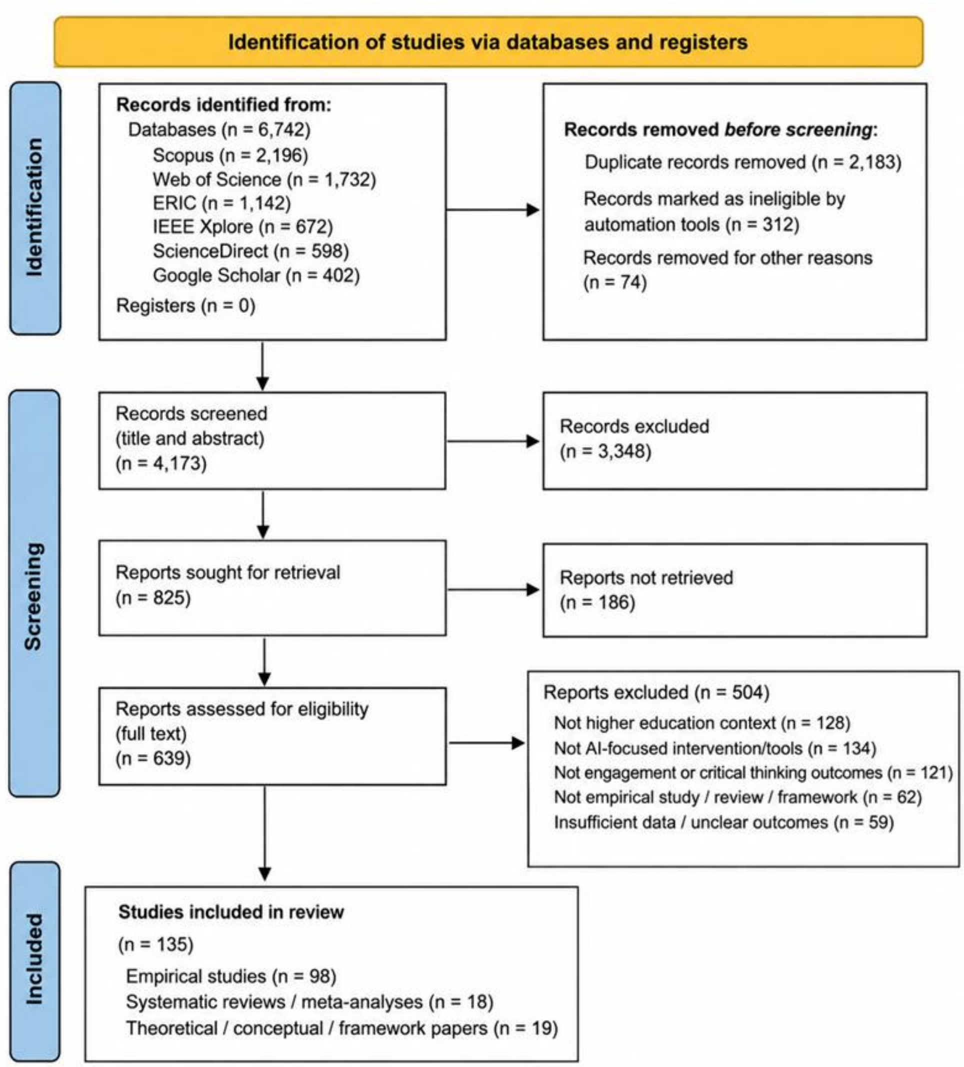

Figure 1. PRISMA 2020 flow of study selection

The literature-selection process for the present review is structured according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 framework. PRISMA 2020 provides a standardized approach for reporting the identification, screening, eligibility assessment and inclusion of studies in systematic reviews. The framework is particularly useful for the present review because the literature on AI in higher education is rapidly expanding and encompasses diverse technologies, research designs and educational contexts. The PRISMA process will therefore provide transparency regarding how studies were identified and selected for synthesis.

The identification stage will involve systematic searches of Scopus, Web of Science, ERIC, ScienceDirect, SpringerLink and IEEE Xplore using combinations of terms related to Artificial Intelligence, higher education, AI-based pedagogy, generative AI, student engagement, critical thinking, AI literacy and teacher competence. Google Scholar and backward and forward citation tracking may be used as supplementary sources to identify potentially relevant publications not captured through the principal databases. All retrieved records will be combined and duplicate publications will be removed before screening.

Importantly, the *actual numbers of records should be entered only after the database search has been completed*. The present manuscript should not claim a specific number of identified, screened or included studies without documentary evidence of the search. Accordingly, the PRISMA flow diagram should report the number of records identified from each database, the number of duplicate records removed, the number of records screened, the number excluded at the title and abstract stage, the number of full-text reports assessed, the number excluded with reasons and the final number of studies included in the review.

VI. OVERALL EVIDENCE-BASED INTERPRETATION

Taken together, the reviewed evidence indicates that AI is neither inherently transformative nor inherently detrimental to higher education. Its educational consequences depend on the interaction between technological capabilities, pedagogical design, learner agency, teacher competence and institutional conditions. AI can increase access to individualized assistance, feedback and interactive learning, but these advantages do not necessarily translate into deeper engagement or critical thinking. The strongest emerging argument is therefore that *AI becomes educationally meaningful when it is used as a cognitive and pedagogical partner rather than as a substitute for student thinking*.

This interpretation provides the basis for the proposed *AI–Pedagogy–Engagement–Critical Thinking (AI-PECT) framework*, which will be developed in the next section of the review. The framework positions AI capabilities as the technological foundation, pedagogical mediation as the principal mechanism, learner agency and AI literacy as essential learner-level conditions, and student engagement and critical thinking as major educational outcomes. Teacher AI-TPACK, digital infrastructure, institutional readiness, assessment design and ethical governance are treated as contextual conditions that can strengthen or weaken these relationships. This framework provides a direct conceptual extension of the original manuscript's model linking AI literacy, perceived usefulness, digital infrastructure, AI-based pedagogy, student engagement and critical thinking.

VII. DISCUSSION

Overall, the evidence supports a *pedagogically mediated model of AI-supported learning*. AI provides technological affordances; pedagogy determines how these affordances are converted into learning activities; AI literacy and learner agency determine how students interact with those activities; and teacher competence, assessment design, infrastructure and institutional governance determine the conditions under which the process occurs. Student engagement and critical thinking should consequently be viewed as outcomes of this interconnected system rather than direct consequences of AI adoption.

VIII. RESEARCH GAPS

Despite the rapid growth of research on AI in higher education, several important gaps remain. The first concerns *methodological fragmentation*. Existing studies employ surveys, experiments, interviews, case studies, learning analytics and systematic reviews, making direct comparison difficult. Many studies rely on self-reported perceptions of usefulness or satisfaction rather than objective measures of learning, engagement or critical thinking. This problem limits causal interpretation and makes it difficult to determine whether reported benefits arise from AI itself, novelty effects, improved instructional design or other contextual factors.

The fourth gap involves *cognitive offloading*. Although over-reliance on AI is frequently discussed, empirical evidence measuring how much cognitive work students actually transfer to AI remains limited. Future research should investigate when AI reduces cognitive effort beneficially and when it reduces productive cognitive struggle. This distinction is essential because reduced mental effort can represent either improved efficiency or diminished learning. The finding that ChatGPT can reduce mental effort while improving some learning outcomes demonstrates the importance of examining this issue directly.

The eighth gap concerns *equity and digital inequality*. AI may improve educational access for some learners while creating new inequalities for others. Differences in access to advanced AI systems, internet connectivity, digital skills and institutional support may influence who benefits from AI. Future research should explicitly examine socioeconomic, geographical, linguistic and accessibility dimensions without assuming that AI adoption produces equal opportunities.

The twelfth gap concerns *integrated theoretical models*. Existing studies often investigate one variable at a time, such as perceived usefulness, engagement or academic performance. There is a need for integrated models that simultaneously consider AI capabilities, pedagogy, AI literacy, learner agency, teacher competence, institutional readiness, engagement and critical thinking. The proposed AI-PECT framework addresses this conceptual gap by positioning pedagogy and learner agency as mechanisms linking AI capabilities with educational outcomes.

IX. IMPLICATIONS FOR RESEARCH AND PRACTICE

The findings have several implications for universities and educators. First, institutions should move from technology adoption toward *pedagogical integration*. The key question should not be whether a university uses AI, but whether AI use contributes to clearly defined learning outcomes. Second, AI literacy should become part of higher education curricula across disciplines. Third, faculty-development programmes should provide teachers with practical knowledge concerning AI-supported lesson design, prompt engineering, verification, assessment and ethical use. Fourth, universities should redesign assessment to emphasize reasoning, reflection, oral defence, authentic problem-solving and evidence-based judgement.

For students, AI should be introduced as a tool for exploration and feedback rather than as a replacement for intellectual effort. Students should be encouraged to verify AI-generated information, identify errors, compare responses with scholarly sources and document their use of AI. For institutions, AI governance should integrate privacy, academic integrity, transparency, accessibility and equity. These measures can help ensure that technological innovation remains aligned with the educational mission of higher education.

X. CONCLUSION

Artificial Intelligence is reshaping higher education by introducing new possibilities for personalized learning, interactive support, adaptive instruction, feedback and generative academic assistance. However, the evidence reviewed in this study indicates that AI does not automatically produce meaningful learning. Its educational consequences depend on how technological capabilities are mediated through pedagogy, how actively learners participate in the cognitive process, how effectively teachers integrate AI into disciplinary teaching and how well institutions provide infrastructure, training and responsible governance.

The evidence concerning student engagement is generally encouraging but conditional. AI can increase behavioural, emotional and cognitive engagement when it provides meaningful interaction, personalization, feedback and learner-centred activities. Recent systematic reviews and meta-analyses support positive effects on engagement while also demonstrating considerable variation across contexts and instructional approaches. The evidence concerning critical thinking is similarly promising but more complex. AI can support analysis, evaluation, reflection, argumentation and problem-solving when students critically interrogate AI-generated information. Conversely, unstructured use may encourage cognitive offloading and reduce independent reasoning. Recent systematic evidence therefore supports the importance of scaffolding, inquiry-oriented pedagogy and explicit critical evaluation of AI outputs.

The principal conclusion is therefore that higher education should move from *AI adoption to AI-informed pedagogy*. The objective should not be to maximize student interaction with AI but to maximize meaningful learning while preserving human judgement, creativity, critical thinking and academic responsibility. AI should function as an augmentation of human cognition rather than a replacement for it. This position provides the conceptual foundation for the proposed AI-PECT framework and offers a basis for future empirical research examining how AI literacy, teacher competence, pedagogical design and institutional readiness jointly shape student engagement and critical thinking.

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