Engagement in the LEARN Framework for the Age of Generative AI

Abstract

The rapid integration of Generative Artificial Intelligence (GAI) into higher education presents both transformative opportunities and significant pedagogical challenges. While AI tools enhance personalisation, feedback, and creative exploration, they also risk diminishing deep cognitive engagement, ethical responsibility, and authentic authorship. This paper positions *engagement* as the central mechanism for sustaining meaningful learning in AI-mediated environments through the LEARN framework—Lifelong Learning, Engagement, Active Processing, Reflection, and Neuro-based Design. Drawing on interdisciplinary research from educational psychology, neuroscience, motivation theory, and higher education studies, the paper conceptualises engagement as a multidimensional construct encompassing behavioural, cognitive, emotional, social, and agentic dimensions. The analysis demonstrates that engagement serves as the psychological and neurobiological engine that links motivation, ethical reasoning, metacognition, and sustained learning. Neuroscientific evidence indicates that engaged learning activates attentional networks, dopaminergic reward systems, hippocampal memory consolidation, and prefrontal executive processes—mechanisms essential for deep and durable learning. Within the LEARN framework, engagement enables Active Processing, strengthens Reflection, supports Neuro-based Design, and sustains Lifelong Learning dispositions. The paper further proposes neuroscience-informed assessment redesign strategies that shift from high-stakes performance models toward reflective, formative, and autonomy-supportive practices. Such engagement-centred assessment fosters ethical responsibility, intrinsic motivation, and adaptive expertise in AI-augmented learning contexts. Ultimately, the study argues that engagement is not merely a pedagogical strategy but a neuro-ethical foundation for sustainable higher education in the age of Generative AI.

Keywords: Generative Artificial Intelligence (GAI); Student Engagement; LEARN Framework; Neuro-based Design; Lifelong Learning; Active Processing; Reflective Learning; Assessment Redesign; Metacognitive Scaffolding; Academic Integrity; Higher Education; Neuroeducation; Agentic Engagement; AI-mediated Learning.

1.0 Introduction

The emergence of Generative Artificial Intelligence (GAI) in higher education has transformed the landscape of learning and assessment. While AI offers unprecedented opportunities for content generation and idea exploration, it simultaneously challenges traditional notions of student engagement, authorship, and ethical responsibility [1]. Reliance on AI tools risks reducing deep cognitive involvement and ethical reflection, which are essential for authentic learning outcomes [2]. To address these challenges, educational frameworks must not only integrate AI ethically but also prioritize engagement as the core mechanism linking motivation, cognition, and ethical reasoning. The LEARN framework—comprising Lifelong Learning, Engagement, Active Processing, Reflection, and Neuro-based Design—offers a structured approach to achieving this goal [3]. Engagement serves as the neural and pedagogical engine of the framework, mediating how students interact with content, peers, and AI tools. Engagement is the central, integrative component connecting cognition, emotion, ethics, and behaviour. Neuroscience demonstrates that learning is most effective when students are actively engaged, activating neural circuits related to attention, memory consolidation, and reward processing [4-5]. Engagement is therefore not merely an educational goal—it is a biologically grounded prerequisite for deep learning, ethical reasoning, and sustained motivation.

This paper focuses specifically on Engagement within the LEARN framework. It explores what engagement is, why it is crucial in AI-mediated learning, its neuroscientific foundations, and how it can be harnessed to redesign assessments that foster deep, reflective, and ethical learning. By focusing on engagement, the paper positions learners not as passive consumers of AI-generated content, but as active, motivated, and ethically aware participants in their educational journey.

2.0 Literature Review

2.1 Context of GAI in higher education

The implementation of GAI tools can enhance metacognitive scaffolding in educational contexts. Metacognitive scaffolding promotes self-regulation and reflective practices among students [6]. Through GAI integration, instructors can provide tailored feedback and guidance that prompts learners to actively engage with their cognitive processes, facilitating the acknowledgment of their understanding and the clarification of concepts. Studies indicate that effective online interactions, such as evaluating opinions and elucidating understandings, lead to deeper learning outcomes [6] and highlight the utility of GAI in fostering such interactions by adapting to the learner's needs in real time. In addition to cognitive skills, the emotional and social dimensions of learning play a vital role in shaping students' experiences and academic success. Research shows that emotions deeply influence how we think and learn, our feelings can either fuel our curiosity or hinder our ability to engage with new material [7]. With this in mind, Generative AI (GAI) tools are now being designed to recognize and respond to students' emotional cues. By using emotional intelligence algorithms, these tools can adjust learning content and strategies to better support students' emotional states, helping them stay motivated and retain knowledge more effectively. This integration mirrors insights from neuroscience, which highlights emotion as a key factor in decision-making and applying knowledge beyond the classroom [7]. In this way, GAI could reshape learning environments by making them not just more adaptive, but more empathetic, leading to deeper and more meaningful learning experiences.

GAI also has the potential to ease the workload of educators while enriching students' learning journeys. One prominent example is the use of intelligent tutoring systems (ITS) that provide personalized and interactive support based on a learner's specific needs [8]. These AI tools can offer timely feedback, guide students through complex concepts, and even foster collaboration, which is increasingly valued in modern education. While initial findings are promising, more research is needed to fully understand the long-term impact of these systems in everyday classroom settings [8]. Ultimately, GAI holds exciting promise—not just for making learning more efficient, but for making it more engaging, supportive, and human-centered.

2.2 Challenges to academic integrity and learning

The rise of Generative AI (GAI) has reshaped learning in higher education—but it also brings new threats to academic integrity. Students now have easy access to AI tools that can write essays or solve problems for them. While these tools can be helpful, they also make it harder to know what students really understand. This risks turning education into a checkbox exercise instead of a meaningful learning experience [8]. To counter this, teaching must go beyond checking answers and instead help students think about how they learn. This is where metacognitive scaffolding is essential. By guiding students to reflect on their thinking—rather than blindly trusting AI outputs—educators can strengthen critical thinking and authenticity in learning (Jumaat & Tasir, 2016). Strategies like prompting students to explain their reasoning or offering tailored feedback can reduce overreliance on AI while fostering deeper engagement [9].

Emotions also play a huge role in how students learn and how they behave. When students feel connected and supported, they're more likely to act ethically. A learning environment that values collaboration, empathy, and motivation can help students choose integrity over shortcuts—even when AI tools are just a click away [7]. In short, while GAI presents real challenges, it also opens doors for more personalized and reflective learning. Universities must strike the balance: supporting innovative AI use while teaching students to think critically, reflect deeply, and act with integrity.

2.3 Institutional Responses

Universities are responding to the rise of Generative AI (GAI) by developing thoughtful guidelines that encourage ethical and innovative use of these tools. Rather than banning AI altogether, many institutions are creating policies that discourage cheating while embracing AI's potential to personalize learning and support student success [9]. A key strategy in this effort is metacognitive scaffolding, teaching students to understand their own learning processes. By helping students reflect on how they learn, universities empower them to use AI as a tool rather than a shortcut. This approach not only builds critical thinking skills but also encourages students to take responsibility for their learning [6].

Additionally, institutions are recognizing the importance of the emotional side of learning. Research shows that emotions deeply influence motivation and engagement [7]. By fostering supportive, emotionally aware learning environments, universities can help students use AI responsibly—and with integrity. In short, by combining clear ethical guidelines, reflective learning practices, and emotional support, universities can not only manage GAI's challenges but also harness its benefits to *enhance education.*

3. The LEARN Framework

The rapid diffusion of Generative Artificial Intelligence (GAI) has fundamentally re-shaped how learners interact with knowledge, offering unprecedented access to infor-mation and creative potential, while also presenting challenges to authentic student ef-fort, reflection, and ethical reasoning. In response, the LEARN framework—anchored in the principles of Lifelong Learning, Engagement, Active Processing, Reflection, and Neuro-based Design—provides a structured, neuroeducation-informed approach for in-tegrating AI ethically and meaningfully into assessment design [10]. There are five components in LEARN as shown in Figure 1.

Fig. 1. Components of LEARN [3]

4. Engagement as the Centrepiece of the LEARN Framework

The LEARN framework—Lifelong Learning, Engagement, Active Processing, Reflection, and Neuro-based Design—offers a structured and ethically grounded blueprint for integrating generative AI (GAI) into contemporary learning environments. Among its five components, Engagement occupies a uniquely central position. While Lifelong Learning highlights the learner's long-term developmental orientation, Active Processing emphasizes cognitive manipulation of information, Reflection fosters meta-awareness, and Neuro-based Design aligns learning with brain-based principles, these four components reach their full pedagogical potential only when Engagement is activated. Engagement functions as the psychological engine that drives learners' participation, curiosity, agency, and perseverance across contexts—from formal education to corporate training, from self-directed online learning to AI-mediated instruction.

Across decades of research, engagement has been conceptualized as a multidimensional construct encompassing behavioral, cognitive, emotional, social, and agentic dimensions [11-13]. In the context of the LEARN framework, these dimensions collectively shape how learners interact with GAI tools, construct meaning, regulate their learning, and transfer knowledge into practice. As such, engagement is not merely one component of the LEARN model; rather, it is the integrating force that enables Lifelong Learning, Active Processing, Reflection, and Neuro-based Design to operate synergistically.

4.1 Engagement and Lifelong Learning: Motivation Across the Lifespan

Lifelong Learning refers to an enduring commitment to expanding one's knowledge, competencies, and adaptability throughout life. Research on achievement motivation and value beliefs [14-15] shows that sustained learning depends on learners' ability to regulate motivation, maintain goal-oriented persistence, and derive personal meaning from learning activities. These qualities correspond directly to the major dimensions of engagement—behavioural, cognitive/metacognitive, emotional, and agentic. In the LEARN framework, Lifelong Learning becomes possible only when these forms of engagement work together to sustain curiosity, perseverance, and self-directed growth over time. Therefor here are the elements that should be in the 'Engagement and Lifelong Learning'.

Behavioural Engagement and Lifelong Learning - Behavioural engagement includes observable actions such as participation, consistent effort, persistence, and task completion. For lifelong learners, these behaviours extend beyond short-term compliance and reflect a durable commitment to improvement and mastery. Classic research by [16-18] demonstrates that participation patterns established early in schooling predict long-term academic success, school completion, and persistence in challenging tasks.

Cognitive and Metacognitive Engagement in Lifelong Learning - Cognitive and metacognitive engagement involve deep processing, strategic thinking, reflective judgment, and the regulation of one's own learning. Research on self-regulated learning [15][19] shows that highly engaged learners use elaboration, organization, monitoring, and adaptive strategies to make sense of complex information.

Emotional Engagement and Lifelong Learning - Emotional engagement includes affective responses such as interest, enjoyment, curiosity, value, and belonging. A large body of research shows that positive emotional experiences strongly predict persistence, resilience, and long-term learning motivation [11][13]. Emotional engagement energizes learning behavior and helps learners continue even in the face of difficulty or uncertainty.

Agentic Engagement and Lifelong Learning - Agentic engagement refers to learners' proactive contributions to shaping their learning experience. Unlike behavioral engagement, which centers on participation, agentic engagement involves initiative—asking questions, expressing preferences, seeking challenges, offering ideas, and requesting help [20-22] identifies agentic engagement as a key component of contemporary engagement models, particularly in personalized and learner-centered environments.

4.2 Engagement and Active Processing: Deep Cognitive Investment

Active Processing—another key LEARN component—refers to how learners manipulate, reorganise, and integrate new information. Decades of research show that deep processing only occurs when cognitive and metacognitive engagement is activated.

Cognitive Engagement as a Driver of Active Processing - [15] demonstrated that strategic processing, such as elaboration and critical thinking, directly predicts academic performance. Similarly, the work of [23] emphasised intellectually demanding tasks requiring students to construct knowledge collaboratively. *Metacognitive Engagement and Monitoring* - Self-regulated learning theories [19][24] highlight how learners who monitor their understanding, adjust strategies, and reflect on errors engage in more effective processing. These metacognitive behaviors enable learners to interact with GAI tools critically—evaluating outputs, verifying accuracy, and refining prompts. *Emotional and Social Engagement Supporting Cognitive Investment* - Positive emotions [11] and socially supportive environments [25] increase cognitive persistence. In AI-supported learning, emotional and social engagement amplify the depth of Active Processing by strengthening motivation and promoting collaborative inquiry. Thus, Active Processing is conceptually inseparable from engagement. Engagement enables learners to invest mental energy into complex problems, especially within AI-augmented environments.

4.3 Engagement and Reflection: Meaning-Making and Metacognitive Growth

Reflection—one of the core pillars of the LEARN framework—refers to the process by which learners evaluate their understanding, revisit strategies, and integrate new insights into existing knowledge structures. It serves as a bridge between experience and conceptual understanding, transforming learning events into deeper meaning-making. However, high-quality reflection does not occur automatically. A substantial body of research demonstrates that reflection becomes most powerful when supported by strong engagement—cognitive, emotional, social, and agentic. Engagement provides the motivational, intellectual, and relational resources necessary for sustained reflective thought. Within the LEARN framework, reflection enables learners to integrate AI-generated feedback, monitor their learning trajectories, and develop adaptive expertise over time.

Cognitive and Metacognitive Engagement as the Foundation of Reflective Practice - Cognitive and metacognitive engagement constitute the intellectual backbone of reflection. Metacognitive monitoring—planning, strategy evaluation, error detection, and comprehension checks—allows learners to make sense of their progress and identify gaps in understanding [15][19]. *Emotional Engagement and the Conditions for Reflective Openness* - Reflection requires vulnerability: recognizing mistakes, confronting uncertainty, accepting feedback, and considering alternative viewpoints. Emotional engagement plays a crucial role by fostering feelings of safety, belonging, and intrinsic value in the learning process. Research demonstrates that learners who feel supported by teachers and peers [26-27] are more likely to participate in reflective activities because they perceive the learning environment as non-threatening and respectful. *Agentic Engagement and Self-Initiated Reflective Cycles* - Agentic engagement refers to learners' proactive efforts to shape their own learning experience. In the context of reflection, agentically engaged learners do not wait for external prompts; instead, they actively seek clarification, request feedback, set new goals, and revise strategies [21]. This self-initiated involvement transforms reflection from a passive, teacher-driven requirement into an active, learner-driven process. Integration: *Why Reflection Depends on Engagement* **-** Reflection is strengthened when all dimensions of engagement—cognitive, metacognitive, emotional, social, and agentic—are simultaneously activated. Cognitive engagement provides analytical depth; emotional engagement creates psychological openness; and agentic engagement ensures initiative and sustained commitment. When these forms of engagement converge, reflection evolves into a transformative process that supports metacognitive insight, resilient learning, and adaptive expertise. Within the LEARN framework, reflection is not simply a concluding step of the learning process. Instead, it is a dynamic practice that allows learners to integrate new knowledge, evaluate AI-derived insights, adjust learning strategies, and cultivate self-awareness. Engagement fuels the metacognitive and emotional resources necessary for this high-quality reflective learning, making reflection a cornerstone of effective, ethical, and sustainable learning in AI-enhanced environments.

5. Role of Engagement in the LEARN Framework

In the evolving landscape of higher education, assessment and engagement are increasingly recognised as neurocognitive, ethical, and motivational processes that shape how students learn, think, and develop. Traditional assessment models—often focused on performance and recall—are being re-examined through the lens of neuroscience, which reveals that meaningful learning occurs when cognitive, emotional, and social brain networks are activated in synchrony [7][28]. This perspective positions engagement as a dynamic integrative mechanism that connects teaching, learning, and assessment while also functioning as an ethical regulator that nurtures responsibility, empathy, and integrity. Grounded in self-determination and affective neuroscience theories, this framework emphasises the importance of autonomy, emotional connection, and reflective feedback in sustaining intrinsic motivation and lifelong learning [29-30]. By aligning pedagogical practices with the brain's natural learning architecture, educators and institutions can transform assessment into an instrument of growth rather than judgment. Neuroscience-informed engagement fosters agency, ethical awareness, and deep understanding—qualities that extend far beyond academic achievement. This integrative model calls for a paradigm shift in higher education: one that values neuro-motivational feedback, ethical engagement, and lifelong learning as essential components of a holistic and human-centered educational ecosystem. Ultimately, such an approach promotes not only cognitive excellence but also the cultivation of emotionally intelligent and morally grounded learners prepared for the complexities of the 21st century.

Role of Engagement in Learning Assessment in Higher Education **-** Student engagement plays a central role in the effectiveness of learning assessment within higher education, functioning as both a process and an outcome of meaningful educational experiences. Engagement—cognitive, behavioural, and emotional—enhances students' motivation to participate in assessment activities and deepens their understanding of course content. Active participation in formative and summative assessments promotes self-regulated learning, reflective practice, and metacognitive awareness, allowing students to take ownership of their learning progress [31][35]. When assessment tasks are designed to be authentic, collaborative, and feedback-rich, engagement levels increase, fostering a learning environment where assessment serves as a tool for growth rather than mere evaluation.

From a neuroscience education perspective, engagement as an integrative mechanism aligns with the brain's intrinsic processes of attention, motivation, and memory consolidation. Neuroscientific research shows that emotionally and cognitively engaging learning experiences activate multiple neural networks—particularly within the prefrontal cortex, hippocampus, and limbic system—that enhance synaptic plasticity and long-term retention [7][30]. When assessments are designed to elicit active participation and reflective feedback, they stimulate dopamine-based reward pathways, fostering sustained attention and intrinsic motivation [4] Engagement thus bridges the cognitive and affective dimensions of learning, integrating assessment not only as an evaluative act but as a neurocognitive process that strengthens neural connections through repetition, feedback, and emotional relevance. In higher education, this neuroscientific understanding underscores the importance of designing assessment environments that evoke curiosity, collaboration, and meaningful challenge—conditions known to enhance learning efficacy and brain-based engagement [28].

Dimensions of engagement (behavioural, cognitive, emotional, agentic) - Engagement in education is a multidimensional construct encompassing behavioural, cognitive, emotional, and agentic dimensions that collectively influence learning outcomes. **Behavioural engagement** refers to students' observable participation in academic activities such as attendance, effort, and persistence, reflecting their commitment to institutional expectations [11]. **Cognitive engagement** involves the mental investment and strategic learning approaches students apply to understand and master complex material [36]. **Emotional engagement** reflects affective reactions such as interest, enjoyment, or anxiety toward learning tasks, influencing motivation and persistence [37]. These three dimensions interact dynamically, shaping how students think, feel, and act within learning environments. When nurtured collectively through formative assessment and responsive teaching, they promote deeper learning, intrinsic motivation, and academic resilience.

6. Proposed Research Model and Empirical Validation Pathway

To move the LEARN framework from conceptual articulation to empirical verification, this study proposes a structured research model that operationalizes the theoretical relationships among Generative Artificial Intelligence (GAI) integration, engagement, cognitive transformation processes, and long-term learning outcomes. The model positions student engagement as the central mediating construct through which instructional and assessment design in AI-supported environments influence deep learning and lifelong learning disposition. As illustrated in Figure 2, GAI integration shapes instructional and assessment practices, which in turn activate multidimensional engagement—behavioural, cognitive, emotional, social, and agentic. Engagement subsequently drives active processing and reflection while being ethically regulated within AI-rich contexts, ultimately leading to deep learning outcomes and sustained lifelong learning orientation. This conceptual pathway provides a testable structure for examining how AI can be pedagogically harnessed to promote meaningful and responsible learning rather than superficial performance. Figure 2 shows A conceptual Model Diagram proposed for this framework.

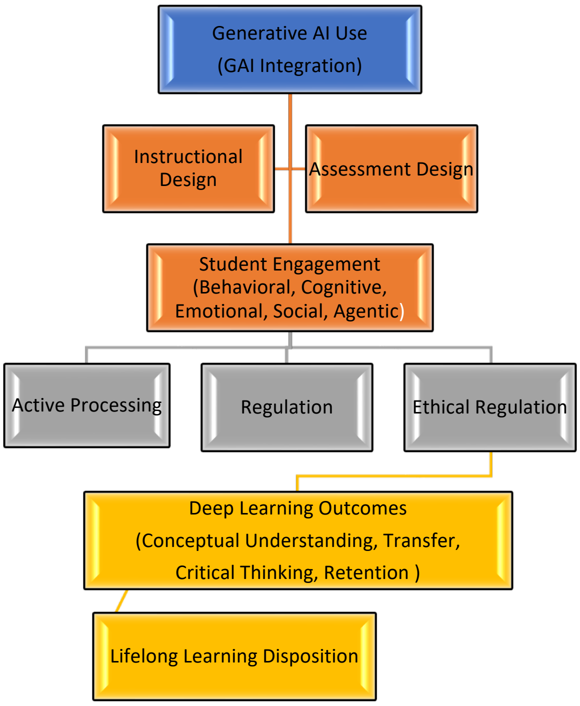

Fig 2. A conceptual Model Diagram proposed for GAI Engagement in LEARN Framework.

6.1 Theoretical Logic of the Model

a. GAI use alone does not directly produce deep learning.
Access to Generative AI (GAI) tools does not automatically produce conceptual understanding or knowledge transfer. According to cognitive psychology, **deep learning requires elaborative processing, integration of prior knowledge, and metacognitive regulation**, not merely exposure to information. Biggs (1987; 2003) [38][39] distinguishes between: Surface learning (reproduction-oriented) and Deep learning (meaning-oriented).

Technology may increase information access, but without cognitive engagement, learners often adopt surface strategies. Kirschner et al. [40] argue that minimally guided learning environments risk superficial processing when learners lack structured scaffolding. Similarly, Mayer [41] demonstrates that multimedia tools enhance learning only when they promote generative processing (selection, organization, integration).

Recent AI-education research confirms this concern. Holmes et al. [42] warn that AI tools can promote shortcut behaviour when learners outsource thinking rather than engage in knowledge construction. Therefore, GAI is an instructional affordance, not a causal driver of deep learning. The mechanism must lie elsewhere — in how learners cognitively and motivationally engage with AI outputs.

b. Engagement acts as the *central mediating mechanism*.
Engagement theory conceptualizes learning as driven by multidimensional involvement: i. Behavioral (participation); ii. Cognitive (strategic processing); iii. Emotional (interest, value) and, iv. Agentic (proactive contribution). Fredricks et al. [11] define engagement as the observable and internal investment that predicts achievement. Kahu and Nelson (2018) [35] argue that engagement mediates institutional practices and student outcomes. Self-determination theory [29] further demonstrates that autonomy, competence, and relatedness activate intrinsic motivation, which predicts deeper learning. Neuroscience supports this mediation logic. Howard-Jones [4] shows that motivated engagement activates dopaminergic reward pathways that sustain attention and memory encoding. Engagement explains *how* AI influences learning — it is the psychological engine that converts tool use into cognitive transformation.

c. Active Processing and Reflection function as secondary mediators.

Active processing involves: Elaboration, Organization and Integration. According to generative learning theory [43], learning improves when learners actively construct meaning. Pintrich and De Groot [15] show that metacognitive strategy use predicts academic performance. Without active manipulation of AI outputs (e.g., critique, revision, integration), learners remain passive recipients.

Whereas Reflection enables: Error detection, Strategy adjustment and Conceptual restructuring. Zimmerman [19] emphasizes self-regulated learning cycles (forethought, performance, self-reflection). Boud and Molloy [44] show that dialogic feedback and reflection enhance higher-order learning. In AI contexts, reflection is crucial for: Evaluating AI accuracy, recognising bias, Integrating AI insights critically. Engagement initiates learning, but active processing and reflection deepen it. They are secondary mediators translating engagement into conceptual mastery.

d. Ethical Regulation moderates outcomes in AI-rich environments.

AI introduces ethical complexity: Authorship ambiguity, Overreliance risks, Bias amplification. Klemenčič (2017) [45] argues that engagement fosters ethical responsibility and institutional trust. Research on academic integrity [46] shows that relational engagement predicts ethical behaviour. Immordino-Yang and Damasio [7] demonstrate that moral reasoning is emotionally grounded — ethical engagement is neurobiologically embedded.

Thus, ethical engagement moderates learning outcomes: High ethical engagement → critical AI use Low ethical engagement → shortcut behaviour. Ethical regulation does not directly cause deep learning, but it conditions whether AI is used constructively or superficially. Thus, it functions as a moderator.

e. Deep learning contributes to lifelong learning orientation.

Deep learning fosters, Conceptual transfer, Intrinsic motivation and Intellectual curiosity. Biggs [39] links deep approaches to sustainable understanding. Deci and Ryan [29] show that intrinsic motivation predicts persistence beyond formal education. Howard-Jones [4] notes that curiosity-driven learning strengthens long-term neural pathways. Lifelong learning is associated with: Self-regulation; Metacognition; and Adaptive expertise. These traits develop through deep, meaningful engagement — not surface performance. Deep learning experiences cultivate durable motivational and cognitive dispositions that extend beyond single courses

Therefore, the integrated theoretical chain explains how Generative Artificial Intelligence (GAI) influences meaningful learning outcomes through a structured psychological and cognitive pathway rather than through direct technological exposure.

6.2 Testable Propositions

There are six empirically testable propositions suitable for structural equation modeling (SEM), mediation analysis, or longitudinal modeling.

Proposition 1 (*Direct Effect*) - Generative AI integration in instructional and assessment design positively predicts student engagement when autonomy-supportive and reflective scaffolds are embedded.

Proposition 2 (*Mediation*) - Student engagement mediates the relationship between Generative AI use and deep learning outcomes: *GAI → Engagement → Deep Learning*

Proposition 3 (*Multi-Dimensional Engagement*) - Cognitive and agentic engagement will show stronger predictive effects on deep learning outcomes than behavioural engagement alone.

Proposition 4 (*Reflection Pathway*) - The relationship between engagement and deep learning is partially mediated by reflective practices: *Engagement → Reflection → Deep Learning*

Proposition 5 (*Ethical Moderation*) - Ethical engagement moderates the relationship between AI use and learning outcomes, such that higher ethical engagement reduces superficial reliance on AI outputs.

Proposition 6 (*Longitudinal Impact*) - Sustained engagement in AI-supported environments predicts growth in lifelong learning dispositions over time.

Collectively, these six propositions provide a coherent and empirically testable structure for validating the LEARN framework in AI-mediated learning environments. They articulate not only the direct influence of GAI integration on engagement but also the mediating and moderating mechanisms through which deep learning and lifelong learning dispositions emerge. By specifying engagement as the central explanatory pathway—enhanced by reflection and ethically regulated within AI-rich contexts—the model advances beyond descriptive claims toward a structurally testable theory. Empirical examination through structural equation modelling, mediation analysis, and longitudinal designs will enable rigorous evaluation of how Generative AI can be pedagogically harnessed to promote sustained, responsible, and conceptually meaningful learning outcomes.

6.3 Suggested Methodological Pathways

The proposed **mixed-methods design** represents an integrated empirical strategy aimed at validating the theoretical structure of the LEARN framework while simultaneously uncovering the underlying mechanisms of engagement in AI-mediated learning environments. This design is particularly appropriate because the LEARN framework is multidimensional, neuro-educational, and ethically grounded — meaning it requires both quantitative structural testing and qualitative process exploration.

Why mixed methods is recommended for initial validation? The LEARN framework proposes that: Engagement mediates the relationship between Generative AI use and deep learning outcomes. This is a '**causal-structural claim'**, which requires, quantitative validation (to test structural relationships) and qualitative evidence (to understand how engagement manifests in AI contexts). Mixed methods ensure statistical validation of mediation effects and contextual understanding of student behaviour, reflection, and ethical reasoning. Table 1 shows the suggestions of mixed-method design, recommended for initial validation.

Table 1: Suggestions of mixed-method design, recommended for initial validation

Quantitative Component	
Instruments	Data Analysis
• Student Engagement Scale (Fredricks et al., 2004 adapted) • Agentic Engagement Scale (Reeve & Tseng, 2011) • Deep Learning Scale (Biggs) • Academic Integrity/AI-use reflection scale	• Structural Equation Modeling (SEM) • Mediation analysis • Multi-group analysis (AI-heavy vs AI-guided conditions)
Qualitative Component	
• Reflective journals documenting AI usage • AI-prompt refinement logs • Focus group interviews on ethical reasoning	
Purpose	
• Validate mediating role of engagement • Identify engagement mechanisms in AI contexts	

A mixed-methods design is therefore necessary to rigorously evaluate the LEARN framework's central mediation claim. Quantitative analyses establish whether engagement statistically mediates the relationship between GAI use and deep learning, while qualitative data illuminate how engagement manifests through reflection, prompt refinement, and ethical reasoning in authentic contexts. This integrated approach strengthens both the explanatory validity and practical applicability of the framework in AI-mediated higher education environments.

7. Implications and Recommendations

From pedagogical Implications, the integration of Generative Artificial Intelligence (GAI) into higher education necessitates a shift from performance-driven instruction toward process-oriented, curiosity-based pedagogy. Educators should reposition GAI as a *partner in cognitive exploration* rather than a shortcut to polished products. Learning tasks need to reward the *thinking process*—how students interrogate, critique, and refine AI-generated content—rather than the outcome alone. Formative feedback loops, reflective checkpoints, and peer discussion sessions reinforce metacognitive awareness and intrinsic motivation [29][47]. Within this paradigm, teachers act as learning mentors who scaffold inquiry and guide ethical reasoning, aligning with the "N" (Neuro-based Design) and "R" (Reflection) components of the LEARN framework [3]. Scaffolding tasks that involve the critique and improvement of AI outputs stimulate higher-order cognitive processing and align with Bloom's revised taxonomy (Krathwohl, 2002). Collaborative learning around AI fosters social engagement, enhancing oxytocin-mediated trust and cooperative learning [48]. Pedagogically, AI-enabled learning environments should foster epistemic curiosity and self-regulated learning, ensuring that students remain active constructors of knowledge in a technology-rich world [4-5].

From neuroeducation implications, LEARN framework aligns GAI-supported learning with the biological mechanisms of motivation, attention, and social cognition. Engagement activates neural networks within the prefrontal cortex, hippocampus, and ventral striatum, which support reward anticipation, working memory, and sustained attention [49]. Curiosity-driven exploration, rather than rote consumption of AI content, stimulates dopamine release and strengthens hippocampal encoding, promoting long-term retention [47]. Learning environments that provide autonomy, meaningful challenge, and immediate feedback engage executive control systems, supporting goal-directed behaviour and cognitive flexibility [50]. Reflective journaling and mentoring sessions stimulate the anterior cingulate cortex, reinforcing self-monitoring and emotional regulation [51]. Mentoring also engages the default mode network, which underpins empathy, trust, and relational learning [52]. Thus, neuroeducation within the LEARN framework bridges theory and biology, ensuring that AI-assisted learning remains emotionally resonant, socially grounded, and cognitively durable [4][7].

For policy implications, the rise of GAI in education demands clear, future-proof policies that safeguard academic integrity, ethical practice, and inclusive access. At the institutional level, universities must establish transparent guidelines that articulate acceptable and unacceptable uses of AI in coursework, assessment, and research. Policies should emphasize responsible engagement requiring students to document how AI is used in their learning process, justify the appropriateness of that use, and acknowledge limitations or inaccuracies [53]. Such reflective accountability aligns with the "R" (Reflection) and "E" (Ethical Engagement) pillars of the LEARN framework [54].

Finally, national and institutional bodies should collaborate to create professional development standards ensuring that educators are AI-literate, pedagogically prepared, and ethically informed. Policies must evolve as rapidly as technology, requiring ongoing review cycles and cross-sector collaboration among educators, neuroscientists, technologists, and legal experts [55].

8. Conclusion

The emergence of Generative Artificial Intelligence has accelerated the need to rethink engagement, assessment, and ethical responsibility in higher education. This paper has argued that engagement is not a peripheral instructional goal but the integrative core of the LEARN framework and the neurobiological foundation of meaningful learning. Across behavioral, cognitive, emotional, social, and agentic dimensions, engagement activates the neural systems responsible for attention, motivation, reflection, and long-term memory consolidation. Without engagement, even technologically advanced AI-supported environments risk producing superficial learning and diminished ethical awareness. Within the LEARN framework, engagement enables Lifelong Learning by sustaining intrinsic motivation and self-regulation across contexts. It drives Active Processing by encouraging deep cognitive investment and critical evaluation of AI-generated outputs. It strengthens Reflection by supporting metacognitive monitoring and ethical discernment. It operationalizes Neuro-based Design by aligning instructional practices with the brain's attentional, emotional, and reward systems. In this way, engagement functions simultaneously as a cognitive catalyst, motivational driver, ethical regulator, and integrative bridge between pedagogy and neuroscience.

The redesign of assessment practices emerges as a critical application of this framework. Engagement-centered assessment—characterized by formative feedback, reflective documentation of AI use, collaborative inquiry, and autonomy-supportive design—transforms evaluation into a neurocognitive process of growth rather than judgment. Such approaches cultivate agency, integrity, and adaptive expertise, preparing learners to navigate AI-rich environments responsibly and creatively. Future research should empirically validate the LEARN framework across diverse institutional and cultural contexts, examine measurable neurocognitive indicators of engagement in AI-mediated learning, and explore longitudinal effects on ethical reasoning and lifelong learning dispositions. As higher education continues to evolve in the age of Generative AI, engagement must remain the central organizing principle—ensuring that technology amplifies, rather than replaces, the human capacities for curiosity, reflection, collaboration, and moral responsibility.

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