Psychology and Behavioral Science
International Journal
ISSN 2474-7688

Juniper Publishers
key to the Researchers

Conceptual Paper
Volume 22 Issue 3 - November 2024
DOI: 10.19080/PBSIJ.2024.22.556090

Psychol Behav Sci Int J

ECOLE-AI: Advancing EFL Learning with Cognitive Theory and Entangled Cognition in the AI Era

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Submission: November 06, 2024; **Published:** November 14, 2024

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Abstract

The cognitive theory of multimedia learning (CTML) is a fundamental principle in multimedia education. It highlights the need for cognitive alignment between teaching content and various learner capabilities, which are essential for enhancing the educational experience. However, the rise of sophisticated artificial intelligence (AI) technologies has led to the creation of new models, including the cognitive-affective-social theory of learning in the digital environment (CASTLE), which expands traditional views by incorporating emotional and social factors alongside cognitive processes, thereby recognizing the complex nature of modern learning. As the use of AI in learning English as a foreign language (EFL) is gaining popularity, this paper presents an entangled cognition in learning EFL with AI (ECOLE-AI) framework. The framework integrates elements from both CTML and CASTLE, focusing on the concept of "entangled cognition," especially in AI-driven EFL learning environments. ECOLE-AI aims to clarify the interactive dynamics among EFL learners, AI tools, and sociocultural contexts of learning. Consequently, it advocates for personalized and adaptive teaching strategies to address the diverse needs of learners in real time. Furthermore, ECOLE-AI reconsiders the role of AI in EFL learning. It positions AI as a catalyst for enriching the cognitive, emotional, and social aspects of EFL learning in a globally interconnected environment. This approach promotes an understanding of education that acknowledges the intricacies of contemporary learning spaces.

Keywords: Artificial Intelligence; Multimedia Learning; Cognitive Theory; Entangled Cognition; EFL Learning

Abbreviations: CTML: Cognitive Theory of Multimedia Learning; AI: Artificial Intelligence; CASTLE: Cognitive-Affective-Social Theory of Learning in the Digital Environment; EFL: English as a Foreign Language; CLT: cognitive load theory

Introduction

The field of multimedia learning has been significantly influenced by the cognitive theory of multimedia learning (CTML) Mayer [1,2], which proposes that effective learning occurs only when the incoming information aligns with the cognitive abilities of the human mind. CTML rests on three principles: the existence of dual channels for visual and auditory processing, limited capacity of the working memory, and active role of learners in forming mental constructs Mayer [3]. The essence of CTML is that optimal information presentation involves the choice of relevant words and images, organizing them into coherent verbal and visual formats, and jointly linking these formats to the learner's preexisting knowledge. Empirical studies supporting CTML have demonstrated its effectiveness in improving learning outcomes Bechtold [4], Mayer [2]. Prior research has identified the "modality effect" Low [5], wherein using both visual and auditory channels causes better learning outcomes than relying only on one modality Schneider et al.[6] ; Mayer [3] ; Ginns [7]. However, recent academic work calls for extending the scope of CTML as new technologies, such as artificial intelligence (AI), have reshaped our interactions with digital content Borboni et al. [8] ; Cavanagh & Kiersch [9]. Schneider et al.[6] Developed the cognitive–affective–social theory of learning in the digital environment (CASTLE) framework, which proposes a more comprehensive model that includes the emotional and social aspects of learning alongside the cognitive elements emphasized by CTML. This broader framework accounts for the fact that learning should occur beyond cognitive functions, affecting and being affected by other variables including emotional states and social contexts. As language learning is increasingly incorporating

AI technologies-such as intelligent tutoring systems and adaptive learning platforms-it is necessary to develop new theoretical models Karataş et al. [10]; Son et al.[11]. These should account for the distinct characteristics of AI (in the present study, AI specifically refers to generative AI or GenAI) being used for language learning, specifically, natural language processing Chen [12]and large language models Jeon & Lee [13]; Jeon et al. [14]; Wang & Raynolds [15]; Wang & Wang [16], which have undergone extensive training on vast datasets to produce human-like text, respond to questions, and execute various language-related tasks with exceptional precision Jauhiainen & Guerra [17].

AI plays a critical role in English as a foreign language (EFL) learning, by enabling personalized and adaptive learning experiences that cater to the individual student needs Dai & Liu [18]; Dong et al. [19]; Jeon[20]. AI-powered technologies, such as intelligent tutoring systems and chatbots, offer tailored content, real-time feedback, and interactive practices, thereby enhancing the overall learning process Jeon[20]. By analyzing students' learning styles and proficiency levels, AI can adjust the pace and delivery of content, thereby increasing student engagement and motivation Kamalov et al. [21]. Additionally, AI-driven tools provide opportunities for students to practice conversational skills in simulated real-life scenarios, thereby improving their language acquisition and communication abilities. Although AI has been found as effective applications in EFL learning, its role in transforming educational practices to improve learning and cognitive engagement has only recently become the focus of substantial interest Jiang [22]. Consequently, prior cognitive research may not have considered the transformative effects that AI could have on learners' cognitive development, particularly in EFL learning. Gaps exist in previously developed frameworks. The proposed entangled cognition in learning EFL with AI ("ECOLE-AI") framework builds on both CTML and CASTLE while integrating concepts from the emerging field of "entangled cognition." The concept of entangled cognition suggests that human cognition is built through interactions with both technological and external environments. ECOLE-AI particularly focuses on the concept of entangled cognition Aguayo, et al. [23] within the context of learning EFL using AI-powered tools. It acknowledges that language acquisition involves more than mere information transfer; it is a complex and dynamic process that is intricately linked to technological, social, and cultural contexts Hiver et al. [24] ; van Dijk et al. [25]. By taking an entangled cognition approach, the ECOLE-AI framework emphasizes the interdependent elements of the cognitive, emotional, and social facets of learning in AI-enhanced language education settings Ahmed, et al. [26]; Almutairi et al. [27]; Uysal & Yüksel [28].

Furthermore, this framework outlines the necessity for context-aware pedagogies that can adapt to learners' individual needs while fostering collaborative and experiential learning. This encourages educators to exploit environments in which students can engage with AI tools, making them more than passive recipients of information during the learning process. Thus, the ECOLE-AI model advocates for integrating feedback loops derived from continuous interactions with the context rendered by AI in EFL learning. This iterative process enables learners to refine their language skills in real-time, addressing their learning challenges while leveraging the adaptive capabilities of AI technologies Biswas & Bhattacharya [29]; Slamet [30]. Additionally, it is essential to address ethical considerations regarding the use of AI in education Roshanaei et al. [31]. Data privacy, algorithmic bias, and the digital divide can impede the equitable application of AI technologies in language learning Anis [32]; Atobatele et al. [33]. Therefore, a comprehensive ethical framework should accompany the ECOLE-AI model to ensure that all learners can access the same high-quality resources and support regardless of their background. Ultimately, the ECOLE-AI framework seeks to redefine language learning by integrating AI, pedagogical strategies, and reflective practices, thereby paving the way for a more holistic and responsive educational paradigm that meets the needs of today's diverse learners. In addition to this stream of development, it is imperative to remain vigilant in the efforts to evaluate and adapt these methodologies, thereby fostering an environment that nurtures language acquisition through collaboration and innovation.

Continuous professional development of educators will play a pivotal role in the successful implementation of the ECOLE-AI framework by equipping teachers with the necessary skills and knowledge to effectively utilize it. Such investment in teacher training empowers instructors and fosters a culture of adaptability and resilience in the face of rapid technological advancement Chaudhry & Kazim [34]. Furthermore, ongoing research and data collection will be essential to assess the impact of AI on language learning outcomes. Feedback loops that incorporate learner experiences and instructional practices will provide valuable insights into the effectiveness of the ECOLE-AI model. This iterative approach will enable us to refine our strategies, ensuring that we remain aligned with the evolving needs of learners and intricacies of language acquisition. Entangled cognition and AI connect significantly, extending our current understanding of cognitive processes Author [35]. This intersection encourages researchers to reconsider traditional intelligence paradigms by considering how AI can assist human cognitive abilities. By examining these connections, advancements in technology have enhanced our understanding of the mind and offered innovative solutions to complex problems across diverse fields. Furthermore, the implications of such development extend beyond academia, influencing ethical discussions around autonomy, decision-making, and the future of human-AI collaboration. As we envisage the future of education, embracing a collaborative approach that includes stakeholders from various sectors-educators, technologists, policymakers, and importantly, learners themselves–is vital. By fostering partnerships and sharing best practices, we can cultivate a rich ecosystem that advances language learning and champions inclusivity and equity in education. Through these concerted efforts, we can

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unlock the transformative potential of AI in shaping the linguistic competencies of global citizens.

Literature Review

Prior Theories on Cognition in the Era of Technology-Enhanced Language Learning

The introduction of cognitive theory has sparked vigorous and ongoing discussions within the academic community. In digital education, particularly multimedia presentations, the cognitive load theory (CLT) Sweller [36] has been extended through various developments and applications. These include the CTML by Mayer [37], cognitive–affective theory of learning with multimedia (CATLM) by Moreno and Mayer [38], integrated cognitive–affective theory of learning with media (ICATLM) by Plass and Kaplan [39], and CASTLE by Schneider et al.[6]. Table 1 presents an overview of these models and their frameworks. Historically, these theories have evaluated and developed the cognitive aspects of technology-enhanced or multimedia learning. Since Moreno and Mayer [38] work, there has been an increasing focus on incorporating motivational and emotional factors into models, acknowledging the interactive effects of cognition and emotion. Emotions have been found to play a critical role in motivation, cognition, perception, attention, creativity, learning, and decision-making (Bhise et al., 2020; Bian et al., 2018) and are crucial in technology-enhanced learning contexts Cheng et al. [40]; Ma [41]. Plass and Kaplan [39] further integrated concepts from Moreno and Mayer's [38] CATLM and emphasized the interaction between cognitive and emotional processes in multimedia learning environments to develop the model of Integrated cognitive–affective theory of learning with media (ICATLM). Schneider et al. [6] cognitive–affective–social theory of learning in digital environments (CASTLE) extends and enriches the ICATLM by including a social dimension in the understanding of an individual's learning processes in digital environments, providing a more comprehensive view of one's learning experience. Nevertheless, these frameworks consider cognition as an independent element, separate from the affective and social dimensions of learning processes. This has resulted in inherent gaps within these models, particularly in the AI era, wherein cognition should be embedded, while other factors are functional.

Table 1: Overview of cognitive models in digital environments.

Model	Pros	Cons
Cognitive theory of multimedia learning (CTML)	1. Focuses on cognitive processes such as selecting, organizing, and integrating information.	1. Neglects social and emotional factors.
	2. Provides clear guidelines for designing effective multimedia instruction.	2. Presents learning as static and linear, not reflecting the dynamic nature of real-world learning.
Cognitive–affective theory of learning with multimedia (CATLM)	1. Integrates emotional and motivational aspects into cognitive processing.	1. Insufficiently emphasizes social interactions.
	2. Recognizes the role of affective states in enhancing learning outcomes.	2. Designing multimedia that effectively balances cognitive and affective elements is complex.
Integrated cognitive–affective theory of learning with media (ICATLM)	1. Combines cognitive and affective processes for a more holistic approach.	1. Implementation can be challenging owing to the need for a sophisticated design.
	2. Addresses both emotional and cognitive load.	2. Limited empirical validation compared with CTML.
Cognitive–affective–social theory of learning in digital environments (CASTLE)	1. Incorporates social cues and interactions, enhancing motivation and engagement.	1. It is complex to design and implement effectively.
	2. Reflects the complex, dynamic nature of learning in digital environments.	2. Requires careful consideration of social dynamics and their impact on learning.
		3. An explanation of emerging technologies' role in the learning process needs to be provided.

Gaps in Existing Models

The CTML is valuable for understanding how learners process multimedia content. However, its application to EFL learners reveals several limitations Wang & Reynolds [15]. One significant gap is the CTML's focus on cognitive processes, such as selecting, organizing, and integrating information, while overlooking the social and emotional aspects of learning. These factors, including learner motivation and engagement, are crucial for successful educational outcomes De Freitas & Neumann [42]; Mayer [2]; Schneider et al. [6]. Effective learning often hinges on these dimensions, suggesting that a model that incorporates them could provide a more nuanced understanding of the learning process Schneider et al. [6]. Another limitation of CTML is its portrayal of learning as either static or linear. This view captures the dynamic and non-linear nature of multimedia learning environments Cavanagh & Kiersch [9]. Learning is often iterative and adaptive, and models that reflect this complexity are required to effectively address real-world learning scenarios Cavanagh & Kiersch [9]. Additionally, CTML tends to use a one-size-fits-all approach without accounting for individual differences in prior knowledge, cognitive abilities, or learning styles. This limits its effectiveness in

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diverse learner populations. Research indicates that personalized learning approaches cater to individual needs and are often more successful (Brusilovsky & Millán, 2021). Incorporating individual variability into multimedia learning models can enhance their applicability and impact. CASTLE was introduced in 2021 to address these shortcomings. It aims to integrate the cognitive, affective, and social dimensions of learning Schneider et al. [6]. Despite its comprehensive approach, CASTLE also has limitations. Notably, it requires a robust integration of CLT, which is crucial for understanding how learners handle complex or overloaded information in digital environments Sweller [43]. Further exploration of CLT principles within CASTLE is required to strengthen its framework. Moreover, CASTLE is relatively new and lacks extensive empirical validation, necessitating further research to confirm its effectiveness in various contexts Schneider et al. [6]. Accurately measuring social and emotional processes in digital learning environments remains challenging and often relies on subjective self-reports (Martin et al. 2022). The development of objective measurement tools can help address this issue. In summary, although CTML and CASTLE offer valuable insights, addressing their limitations can significantly enhance our understanding and application of multimedia learning models.

The 4E Cognition + GenAI = ECOLE-AI

The 4E cognition framework can be traced back to the 1990s. This framework asserts that cognitive functions are not limited to the brain, but are embodied, embedded, enacted, and extended Carney [44]. This shift in perspective challenges conventional cognitive science, which typically views cognition as a computational activity confined to the brain Newman et al. [45]. By adopting these principles, 4E cognition offers a comprehensive perspective on mental processes. It emphasizes the critical roles of the body, environment, and external resources in influencing cognitive experiences. AI has also contributed to refining cognitive theories. Techniques such as reinforcement learning, which are rooted in behavioral psychology, have been adapted to develop AI systems capable of complex decision-making. Conversely, AI models have generated new hypotheses regarding the neural mechanisms underlying cognitive functions, which have been empirically tested and validated. The 4E cognition framework is robust in incorporating AI into education. Presently, as AI is increasingly enhancing learning experiences, 4E cognition stresses the importance of interaction among learners, their surroundings, and cognitive processes. AI can promote embodied learning by developing interactive simulations and virtual environments which students can physically and perceptually engage in, thereby enhancing their comprehension. It can assist embedded cognition by providing real-time, context-specific feedback and resources tailored to individual needs, thus grounding learning in the relevant settings. Through enacted cognition, AI-driven tools can enable learners to actively manipulate and experiment with concepts, thereby fostering a more dynamic and engaging learning process. Finally, extended cognition emphasizes how AI can enhance cognitive abilities by offering external tools and support, such as intelligent tutoring systems and collaborative platforms, which expand the learners' cognitive reach. We explicitly describe the benefits of AI in EFL learning from the perspective of 4E cognition and further propose the ECOLE-AI framework.

Embodied Cognition: Embodied cognition highlights the fact that cognitive functions are fundamentally connected to the body's interactions with the environment. It posits that the mind and body are intertwined with bodily experiences, which are crucial in shaping cognitive processes. Lakoff and Johnson [46] argued that this conceptual framework is primarily metaphorical and rooted in physical experiences. Research has found that GenAI, such as ChatGPT, offers new possibilities for enhancing embodied cognition by providing interactive, personalized, and contextually rich learning experiences. For instance, Holstein et al. [47] found that AI-enhanced personalized learning platforms boost student engagement and improve educational results by catering to individual needs. Further, Wang and Xue [48] discovered that AI-powered conversational agents enhanced language learning results by offering interactive and adaptive practice options.

Embedded Cognition: Embedded cognition refers to cognitive functions situated within a specific context. This perspective highlights that one can only fully grasp cognition by considering the surrounding physical and social environments. Clark and Chalmers [49] introduced the notion of the "extended mind," suggesting that environmental objects can act as extensions of cognitive capabilities. Through its capacity to produce context-appropriate content, GenAI can significantly improve embedded cognition in educational contexts. Samala et al. [50] emphasized the integration of GenAI models within educational environments to facilitate engaging and immersive learning experiences. Furthermore, Wood and Moss [51] discovered that integrating GenAI into a master-level instructional design program increased students' familiarity with the technology and their comprehension of its ethical considerations, resulting in improved cognitive engagement of students.

Enacted Cognition: Enacted cognition highlights the importance of actions in cognitive functions. This posits that cognitive processes emerge from active exchanges between individuals and their surroundings. Varela et al. [52] argued that cognition represents not only reality but also constant engagement. This perspective highlights the importance of actions in cognitive functioning. GenAI can significantly improve cognition in educational environments by offering engaging and tailored learning experiences, modifying content based on student interactions, and delivering customized feedback and support. Shapiro and Stolz [53] examined the application of embodied and enacted cognitive theories in educational settings to improve student learning using interactive and adaptable methods. This

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adaptability resonates with the tenets of enacted cognition, wherein learning is recognized as an active endeavor involving ongoing engagement with the environment.

Extended Cognition: Extended cognition suggests that mental processes extend beyond an individual's mind to encompass tools, technologies, and surroundings Adam & Kallestrup [54]. It highlights that cognition is not limited to the brain but is spread across external instruments and social engagement. This perspective aligns closely with the extended mind concept, suggesting that cognitive processes are distributed across the brain, body, and environment Heinrichs [55]; Sprevak [56]. GenAI can significantly enhance extended cognition in educational environments by providing interactive, adaptive, and contextually appropriate learning experiences.

The Proposed Framework

Integrating GenAI into EFL learning requires a sophisticated understanding of human learning processes and technological interactions Yan et al. [57]. The concepts of entangled cognition and 4E cognition are particularly significant. 4E cognition posits that cognitive processes extend beyond the brain, emphasizing that our physical bodies, environments, and interactions significantly influence thinking and learning. Entangled cognition expands this idea by focusing on the connection between cognitive processes and the tools employed in such processes. When engaging with technology, such as GenAI, our cognitive activities merge with those of these tools. We may delegate specific cognitive tasks to technology, which in turn affects our comprehension and execution of the tasks. GenAI can be an invaluable resource for EFL learning Joo [58]; Kim et al. [59]; Liu et al. [60]. It provides students with tailored feedback, generates learning materials, and enhances their communication practices. However, acknowledging the risks associated with cognitive entanglement is essential. If students depend excessively on AI for language production or grammar correction, their cognitive development in language acquisition may suffer. Therefore, it is essential to maintain a balanced approach. Educators should capitalize on the advantages of GenAI while cultivating students' independent language learning abilities and fostering a critical understanding of the impact of technology on their educational journeys. By understanding the principles of entangled and 4E cognition, educators can effectively leverage GenAI to enrich and empower EFL learning experiences. Figure 1 depicts the integration of 4E cognition and GenAI into the learning process, leading to ECOLE-AI.

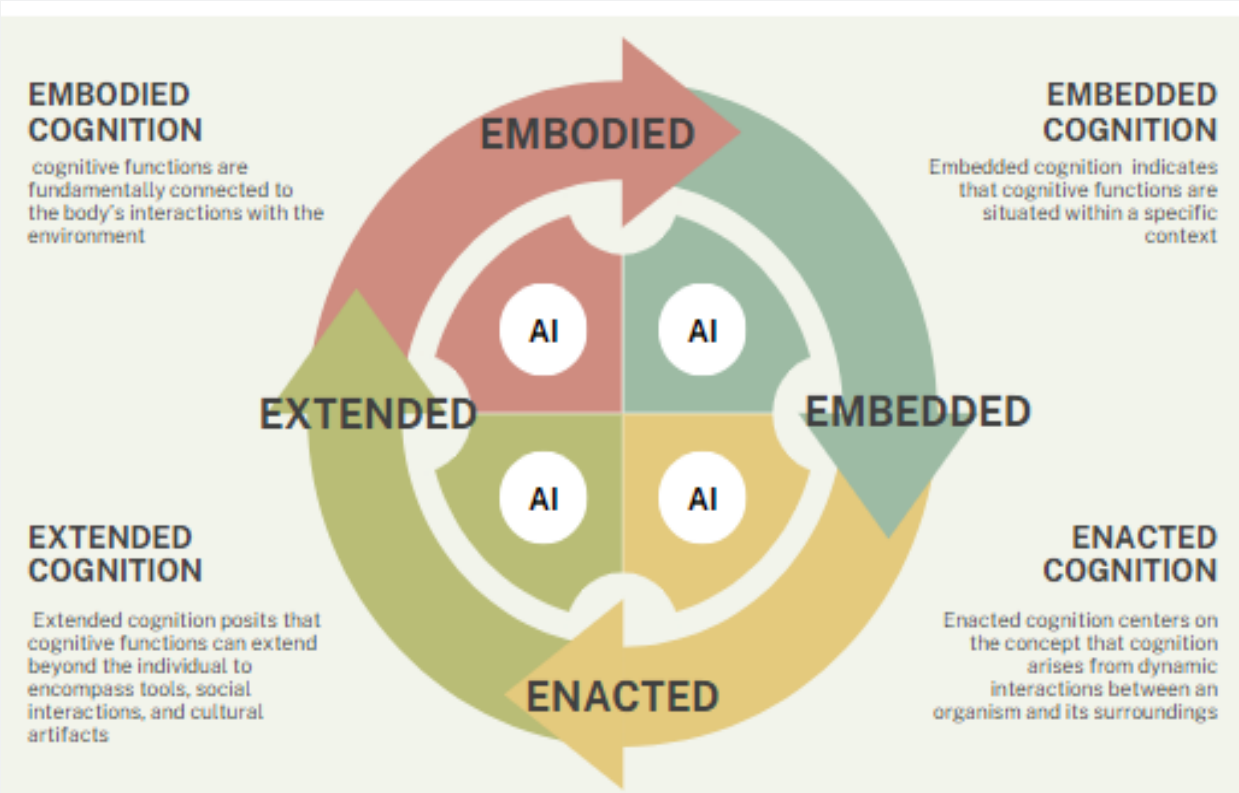

Figure 1: ECOLE-AI framework development through interaction between 4E cognition and GenAI.

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Conclusion

As digital learning environments continue to advance, the ECOLE-AI framework emerges as a robust model that supports language proficiency and fosters the development of critical thinking and metacognitive skills. This dual focus ensures that learners are not merely passive recipients of information, but are actively engaged in their learning processes, cultivating the ability to reflect, analyze, and adapt their strategies of learning. The dynamic nature of this approach equips learners with the tools necessary to make informed decisions about their educational paths, thereby creating a foundation for lifelong learning. The evolution of digital learning environments demands a framework, such as ECOLE-AI, which balances enhancing language proficiency with developing critical thinking and metacognitive skills. This approach empowers learners to actively engage in educational processes and fosters skills beyond language acquisition into broader cognitive and decision-making abilities. The successful implementation of the ECOLE-AI framework requires educators to understand AI technologies and the intricate linguistic challenges inherent in language learning. Educators should receive comprehensive training and continuous professional development to remain attuned to the evolving technological landscape and effectively apply these tools in the classroom. This will ensure that the pedagogical strategies used are aligned with the framework's goals and are adaptable to the diverse needs of learners in various educational contexts. Moreover, seamlessly integrating AI with pedagogical practices will allow teachers to create more personalized learning experiences, enhancing learner engagement and retention. In addition to pedagogical concerns, the relationship between cognitive processes and AI presents both opportunities and complexities. Integrating AI into learning environments highlights the convergence of human and machine cognitive functions [61].

This synergy opens new avenues for enhancing human cognitive abilities by offering tools to augment learners' problem-solving capacity, pattern recognition, and self-regulation. Simultaneously, AI systems can benefit from insights drawn from human cognition, leading to the development of more advanced, adaptive computational frameworks; some may even draw inspiration from emerging fields such as quantum mechanics. Ongoing research is essential for assessing the long-term effectiveness of the ECOLE-AI framework in diverse educational settings. Educators and policymakers can make evidence-based adjustments to optimize the framework by systematically collecting and analyzing data on learner outcomes, engagement levels, and the efficacy of AI tools in real-world classrooms. This continuous feedback loop, informed by empirical research, can ensure that the framework remains responsive to emerging challenges and opportunities in language education. Furthermore, comparative studies across different cultural and linguistic contexts will provide valuable insights into how the ECOLE-AI framework can be tailored to maximize its global applicability. However, this evolving relationship invites deeper philosophical inquiry into the nature of intelligence. As AI systems become more sophisticated, questions arise on whether intelligence should be regarded solely as a human attribute or as a shared, collaborative essence between biological and artificial entities.

This blurring of boundaries between human and machine cognition compels us to rethink long-held assumptions about the nature of thought, creativity, and decision-making. Ethical considerations must remain at the forefront of these discussions to ensure that the growing interdependence between humans and AI benefits society, without exacerbating existing inequalities or undermining human autonomy. Interdisciplinary collaboration is essential to navigate these challenges. Researchers, educators, technologists, and cognitive scientists should collaborate to build ethical frameworks that guide the development and implementation of AI in education. These collaborations promote best practices and foster an environment in which innovation can thrive without compromising ethical standards. By creating a continuous dialogue between different academic and professional communities, the complexity of this entangled relationship can be harnessed to advance both AI technologies and our understanding of human cognition, ultimately contributing to more equitable and effective global educational outcomes. In conclusion, the ECOLE-AI framework offers an innovative approach to enhancing language education through AI, significantly improving learner outcomes. However, its success depends on a commitment to rigorous professional development, continuous research, and ethical considerations. By addressing these areas, the framework can serve as a model for integrating AI into education in ways that are both effective and responsible, ultimately preparing learners for a future in which technology and human cognition are increasingly interconnected.

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How to cite: Liwei H. ECOLE-AI: Advancing EFL Learning with Cognitive Theory and Entangled Cognition in the AI Era. Psychol Behav Sci Int J. 2024; 22(3): 556090. DOI: 10.19080/PBSIJ.2024.22.556090

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DOI: 10.19080/PBSIJ.2024.22.556090

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