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Between Gesture and Interface: A Cyclical Model for Attention in Digital Ecologies

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Abstract: Digital learning environments reshape how learners perceive, act, and sustain attention across networks of bodies, gestures, interfaces, and material configurations. While online formats expand access, they also reveal persistent difficulties in maintaining attention where cognitive demands, technological affordances, and embodied rhythms misalign. This contribution proposes a conceptual framework grounded in cognitive neuroscience, multimedia learning, and ecological–embodied cognition, conceiving attention as a distributed property of human–technology systems rather than an internal resource. The framework informs a cyclic model linking digital environments, attentional challenges, evidence-based strategies, and cognitive outcomes. To operationalize the model, a pilot MOOC will be developed as a testbed for attentional scaffolding, integrating segmented micro-lessons, structured pauses, micro-feedback, lightweight gamification, and guidance on managing the physical study setting. Its effectiveness will be examined through behavioural traces, brief questionnaires, performance measures, and qualitative feedback. The goal is to refine design principles for cognitively sustainable and ecologically grounded digital learning.

Keywords: attentional ecology; digital learning environments; cognitive sustainability.

1. Introduction

In recent decades, teaching and learning processes have been profoundly reshaped by the progressive integration of digital technologies into educational contexts. This transformation represents a structural shift that has reconfigured learning

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environments, modes of access to knowledge, and forms of student participation, introducing new spatial and temporal arrangements and expanding possibilities for interaction between learners, content, and technological tools (Scarinci, Di Furia, & Peconio, 2023).

Digital learning has consequently become an established dimension of contemporary education, taking multiple forms such as synchronous online teaching, asynchronous e-learning, MOOCs, and immersive environments. While these contexts offer increased flexibility and broader access, they also present challenges, including difficulties in sustaining engagement and high dropout rates, particularly in large-scale programmes (Scarinci et al., 2023). At the same time, the multisensory nature of digital environments increases the complexity of information processing, which may affect attention, comprehension, and depth of learning (Marzano, Vegliante, & Iannotta, 2015).

Within this framework, attention emerges as a critical dimension. Online learning environments require learners to exercise high levels of self-regulation in the absence of the temporal and spatial structures typical of face-to-face instruction (D'Elia, 2024). However, attentional difficulties should not be interpreted solely as individual limitations. Digital environments are complex systems that shape perception, action, and cognitive regulation through their technological and contextual configurations.

In line with this view, the present paper proposes a conceptual framework for understanding and supporting attention in digital learning environments. Drawing on an ecological perspective on cognition, attention is conceptualized as a distributed and situated phenomenon emerging from the dynamic interaction between cognitive processes, bodily engagement, technological configurations, and material contexts.

2. Digital learning and ecologies of cognition

To understand attentional dynamics in digital learning environments, it is necessary to adopt a theoretical perspective that moves beyond an individualistic conception of cognition. Distributed, extended, and embodied cognition offer conceptual tools for interpreting learning as a situated and relational process embedded within material, social, and technological contexts.

Distributed cognition emphasizes that cognitive processes are not confined to the individual mind but are distributed across people, artifacts, and environments through dynamic coordination between internal resources and external supports (Salomon, 1993; Hutchins, 1995). Artifacts play a central role by providing affordances and representational resources that guide attention and action (Norman, 1997), leading to an ecological understanding of knowledge as a cognitive ecosystem in which individuals, tools, and social practices are functionally integrated (Bonaiuti, 2013).

Extended cognition further elaborates this relationship by showing how external resources can become functionally integrated components of cognitive processes when interactions with tools are stable and reliable (Clark & Chalmers, 1998; Clark, 2011; Pinna, 2013). Embodied cognition complements these views by emphasizing the role of sensorimotor experiences, posture, and bodily interaction in shaping perception, action, and meaning-making (Kosmas & Zaphiris, 2018; Sullivan, 2018).

These perspectives are particularly relevant for digital learning environments, which function as sociotechnical systems that shape attention, cognitive load, and learner activity through interfaces, spatial configurations, and usage conventions

(Macedo et al., 2023). Digital learning can therefore be conceptualized as an ecology of cognition in which attentional processes emerge from the coordinated interplay of mind, body, tools, and environment.

3. Attention and neurocognitive constraints in digital learning environments

Interpreting digital learning as an ecology of cognition requires considering the neurocognitive constraints that regulate attentional processes. According to Baddeley's (2000) model, working memory is a limited-capacity system responsible for maintaining and manipulating information during complex cognitive tasks. When multiple information sources are processed simultaneously, cognitive resources may become saturated, affecting attentional stability and learning effectiveness.

This constraint is particularly relevant in digital environments, where information is often presented through continuous and multimodal streams. Cognitive Load Theory explains that learning is most effective when overall load remains compatible with working memory capacity, and that difficulties often arise from how information is presented rather than from content complexity itself (Sweller, 2011; van Merriënboer & Sweller, 2010).

Poorly structured layouts, lack of segmentation, and overlapping communication channels may increase extraneous load, diverting cognitive resources away from meaningful processing (Paas et al., 2003). Neuroimaging evidence further shows that attention relies on coordinated activation of distributed neural networks, which can be disrupted by disorganized or excessively dense environments (Mason & Just, 2009).

Overall, attention should be understood as a dynamic process shaped by both cognitive architecture and environmental conditions. In digital learning contexts, attentional regulation emerges from the interaction between neurocognitive limits and instructional design features.

4. Multimedia design and attentive support

Multimedia design plays a central role in structuring learning experiences compatible with the limits of working memory and attentional regulation. According to Mayer's Cognitive Theory of Multimedia Learning, meaningful learning occurs when learners select relevant information, organize it coherently, and integrate it with prior knowledge within limited processing capacity (Mayer, 2009; 2024).

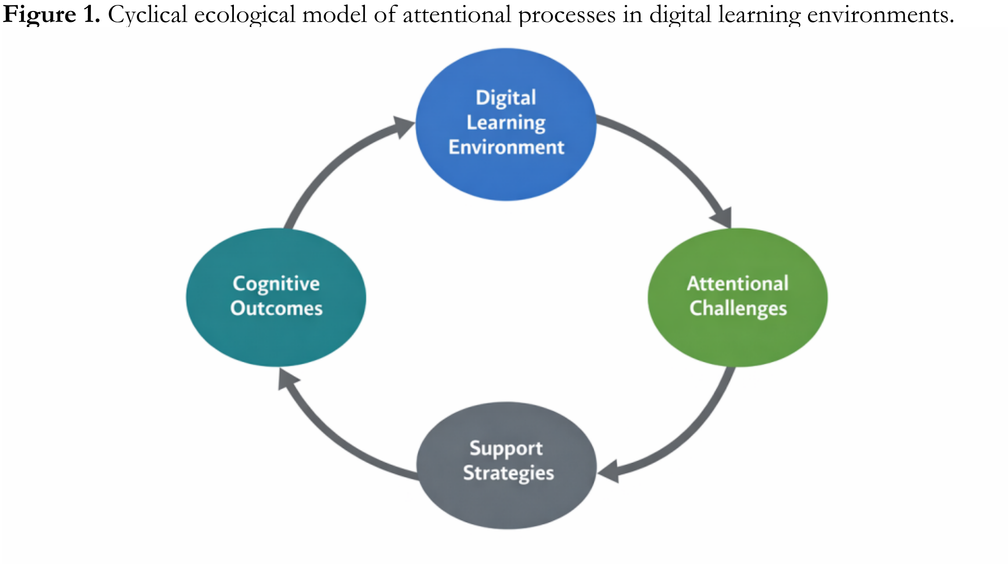
Empirical evidence shows that poorly structured materials increase extraneous cognitive load and interfere with attentional stability, whereas cognitively aligned designs support more efficient allocation of attentional resources (Mayer & Moreno, 2003; Sweller et al., 2011). Design principles such as segmentation, hierarchical organization, and signaling cues promote sustainable processing, especially in asynchronous environments (Mayer, 2014).

More recent research also highlights the role of motivational factors in sustaining engagement, provided that design elements remain aligned with cognitive principles and do not increase extraneous load (Mayer, 2013; Renninger et al., 2018). Multimedia design can therefore be understood as a regulatory mechanism within the cognitive ecology of digital learning.

5. The conceptual framework: an ecological model of attention

This contribution proposes a conceptual framework for interpreting attentional processes in digital learning environments from an ecological perspective on cognition (Hutchins, 1995; Clark, 2011; Bonaiuti, 2013). The framework is conceptual rather than prescriptive in nature: its aim is not to offer a fixed instructional model, but to provide an analytical structure for understanding how attentional difficulties emerge within digital learning ecologies and how they may be addressed through intentional design choices. It integrates insights from neurocognitive constraints (Baddeley, 2000; Sweller, 2011), multimedia design principles (Mayer, 2014), and ecological approaches to learning environments (McCalla, 2004).

Figure 1. Cyclical ecological model of attentional processes in digital learning environments.



As illustrated in **Figure 1**, the framework conceptualizes attention as a cyclical process resulting from the interaction between four interconnected components: the digital learning environment, attentional challenges, support strategies, and cognitive outcomes. Digital environments actively shape attentional dynamics through platform architecture, interface design, content structure, and temporal organization, thereby configuring the conditions under which attention is distributed, sustained, or fragmented (Norman, 1997; Mayer & Moreno, 2003).

The first component, the digital learning environment, refers to the ensemble of technological, representational, and material elements that structure the learning experience, including interfaces, multimodal content, and temporal arrangements. From an ecological perspective, these elements form an adaptive system that continuously interacts with learners' goals, behaviors, and cognitive needs (McCalla, 2004).

The second component concerns attentional challenges, such as cognitive overload, fragmentation of focus, and increased demands for self-regulation. These challenges are understood as relational phenomena emerging from the interaction between learners' cognitive limitations and environmental demands, particularly in hypermedia and self-directed learning contexts (Sweller, 2011; Azevedo et al., 2010).

The third component consists of support strategies, defined as design-oriented interventions aimed at regulating the attentional ecology. These include content segmentation, pacing, structured pauses, feedback mechanisms, and attentional cues, which are known to reduce extraneous cognitive load and stabilize engagement (Mayer, 2013; Mayer, 2014). Research on self-regulated learning in technology-enhanced environments highlights how such design features can scaffold learners' metacognitive, motivational, and behavioral regulation processes (Giannetti, 2006; Azevedo et al., 2010).

The fourth component refers to cognitive outcomes, such as improved attentional stability, reduced overload, enhanced comprehension, and better retention. These outcomes indicate a more balanced coordination between learner and environment and reflect the effectiveness of ecological design choices in supporting sustained engagement (De Vincenzo, 2021).

The cyclical structure of the model highlights how cognitive outcomes inform subsequent adjustments in environmental design, leading to iterative refinements of strategies and configurations. In this sense, attention is conceptualized as a dynamic process continuously shaped through feedback loops between learners and digital environments, rather than as a fixed individual trait.

6. Illustrative example of framework application

To clarify how the proposed framework could be applied in practice, this section presents a hypothetical design scenario based on an asynchronous MOOC developed on a Learning Management System (LMS) such as Canvas. The example illustrates how attentional processes may be supported through coherent design choices, without describing an implemented intervention.

The selection of the platform represents a key element of the learning ecology. According to e-learning design literature, platforms should ensure usability, scalability, interoperability, and accessibility (Davis, 1989; Sun et al., 2008). An LMS such as Canvas supports modular content organization, multimodal delivery, integrated assessment tools, and learning analytics, facilitating attentional regulation and iterative instructional design in large-scale online contexts.

Each module is assumed to follow a backward design structure (Wiggins & McTighe, 2005), beginning with clearly defined learning outcomes and assessment criteria, followed by instructional activities aligned with learner prerequisites, key competences, methodological choices, and formative evaluation tools. This structure promotes coherence between learning goals and transversal skill development.

In asynchronous MOOC environments, learners often face attentional challenges such as cognitive overload, fragmented focus, and sustained self-regulation demands. Cognitive Load Theory guides the organization of materials through content segmentation, progressive pacing, alignment of visual and verbal information, and signaling cues to reduce extraneous load (Sweller, 2011; van Merriënboer & Sweller, 2010; Mayer, 2014). Active pauses with timers may further support attentional recovery.

Universal Design for Learning principles inform the provision of multiple means of representation, engagement, and expression (CAST, 2011), allowing learners to access content through videos, texts, infographics, or audio formats, and to demonstrate learning through diverse assessment modes, while maintaining alignment with common learning objectives.

Gamification elements such as progress indicators, achievement badges, and low-stakes challenges may enhance motivation and persistence without increasing cognitive demands, provided they remain aligned with instructional goals (Deterding et al., 2011; Hamari et al., 2014).

Within this scenario, the four components of the ecological model interact dynamically: the digital environment shapes attentional demands, attentional challenges emerge from learner–environment interactions, support strategies regulate attention, and cognitive outcomes inform iterative design adjustments, illustrating the cyclical nature of the framework.

7. Limitation of the work

The present contribution is subject to several limitations that should be acknowledged. First, the proposed framework is conceptual in nature and has not yet been empirically implemented or validated through experimental or quasi-experimental studies. As a result, the relationships between the model's components, digital learning environments, attentional challenges, support strategies, and cognitive outcomes, remain theoretically grounded rather than empirically tested.

Second, the illustrative application presented in this paper is hypothetical and serves only as an example of how the framework could be operationalized in practice. While it draws on established principles from cognitive load theory, Universal Design for Learning, and instructional design literature, future research is needed to examine how these principles interact in real-world MOOC or LMS-based learning contexts.

Third, the framework does not account for all individual and contextual variables that may influence attentional processes in digital learning environments. Factors such as learners' prior knowledge, motivational profiles, digital literacy, cultural background, and access to technological resources may significantly affect attentional dynamics and were not explicitly modeled in this contribution.

Finally, the ecological perspective adopted in this paper emphasizes systemic interactions between learners and environments, which may limit the framework's direct applicability to highly standardized or rigid instructional settings where design flexibility is constrained.

Despite these limitations, the framework provides a coherent theoretical basis for future empirical investigations and design-oriented studies aimed at improving attentional support in digital learning environments.

8. Conclusion

This paper has addressed the issue of attention in digital learning environments by adopting an ecological perspective on cognition. Moving beyond deficit-based interpretations that attribute attentional difficulties primarily to individual learners, attention has been conceptualized as an emergent phenomenon arising from the interaction between cognitive processes, bodily engagement, technological artefacts, and environmental configurations (Hutchins, 1995; Clark, 2011; Bonaiuti, 2013).

By integrating perspectives from distributed and extended cognition, cognitive psychology, and multimedia learning research, the contribution has highlighted how attentional dynamics are shaped by both neurocognitive constraints and instructional design choices embedded in digital learning environments (Baddeley, 2000; Sweller, 2011; Mayer, 2014). In this regard, attentional difficulties have been interpreted not merely as individual regulatory failures, but as relational outcomes emerging from the interaction between learners and complex sociotechnical environments (Azevedo et al., 2010; McCalla, 2004).

On this basis, a conceptual framework has been proposed to systematize the relationships between digital environments, attentional challenges, support strategies, and cognitive outcomes. The framework emphasizes the role of design-oriented interventions, such as cognitive load regulation, multimodal structuring, and self-regulation scaffolding, in supporting attentional stability and meaningful learning processes (Paas et al., 2003; Mayer & Moreno, 2003; Giannetti, 2006).

The value of the proposed framework lies in its capacity to reconceptualize attention as a relational and systemic process, shifting the focus from individual remediation to environmental design. This shift has relevant implications for the development of cognitively sustainable and inclusive digital learning environments, particularly in contexts that require learners to manage complex information flows and high levels of self-regulation (CAST, 2011; D'Elia, 2024; De Vincenzo, 2021).

While the framework remains conceptual, it provides a coherent theoretical foundation for future empirical investigations and design-oriented research. By foregrounding the ecological nature of attention, this contribution aims to support a more nuanced understanding of digital learning and to inform the intentional design of educational technologies aligned with human cognitive functioning (Scarinci et al., 2023; Sullivan, 2018).

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