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Artificial Intelligence as a Dynamic Cognitive Partner Integrating Working Memory Theory and AI Supported Reading Development in Dyslexia

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Abstract

Artificial intelligence (AI) has rapidly emerged as a promising resource for supporting students with dyslexia. Nevertheless, much of the existing literature examines AI primarily as an assistive technology, with limited attention to the cognitive mechanisms through which it may enhance reading development. This paper addresses that gap by proposing a conceptual framework that integrates Baddeley's multicomponent model of working memory with contemporary AI-supported educational tools. Drawing on research in cognitive psychology, special education, cognitive load theory, Universal Design for Learning (UDL), and self-determination theory, the paper argues that AI should be understood not merely as an instructional aid but as an external cognitive support system that complements and extends the functional capacity of working memory during reading. Specifically, the framework illustrates how AI technologies—including text-to-speech systems, speech recognition, adaptive learning environments, and generative AI applications—may reduce cognitive load while supporting the phonological loop, visuospatial sketchpad, central executive, and episodic buffer. Through this cognitive alignment, AI has the potential to facilitate decoding, comprehension, learner engagement, and reading autonomy among students with dyslexia. The proposed framework contributes to the literature by offering a theoretically grounded perspective that connects cognitive theory with emerging educational technologies. Rather than evaluating the effectiveness of a specific intervention, the paper provides an integrative model to guide future empirical research, instructional design, and the development of AI-supported reading interventions for learners with dyslexia.

Keywords

Artificial Intelligence; Dyslexia; Working Memory; Cognitive Support; Reading Development

1. Introduction

Dyslexia is a common neurodevelopmental learning difficulties, affecting children's ability to acquire accurate and fluent reading skills despite adequate educational opportunities and intellectual abilities. Beyond difficulties in decoding, phonological processing, and word recognition, many students with dyslexia experience challenges in maintaining and integrating linguistic information during reading comprehension. These difficulties are often associated with limitations in cognitive processes, particularly working memory, which plays

a central role in temporarily storing, processing, and integrating information required for successful reading (Baddeley, 2000; Swanson & Alloway, 2012).

Working memory has been recognized as a fundamental cognitive system underlying reading development. According to Baddeley's multicomponent model, working memory consists of four interconnected components: the phonological loop, the visuospatial sketchpad, the central executive, and the episodic buffer (Baddeley, 2000, 2012). Each component contributes uniquely to reading processes, including phonological decoding, attention regulation, integration of semantic information, and construction of coherent meaning. Students with dyslexia frequently demonstrate weaknesses in one or more of these components, which may increase cognitive demands during reading tasks and limit their ability to allocate cognitive resources toward comprehension and higher-order thinking (Gathercole & Alloway, 2008; Peng & Fuchs, 2016).

Traditional approaches to dyslexia intervention have primarily focused on explicit instruction in phonological awareness, decoding strategies, vocabulary development, and reading fluency. Although these approaches have demonstrated effectiveness, many learners continue to experience persistent reading difficulties, suggesting the need for complementary approaches that address the underlying cognitive demands associated with reading (Snowling & Hulme, 2021). Recent developments in artificial intelligence (AI) have introduced new possibilities for supporting learners with dyslexia; however, existing research has often conceptualized AI mainly as an assistive technology rather than as a cognitive mechanism that interacts with learners' underlying cognitive processes.

Artificial intelligence-based educational tools, including adaptive learning systems, text-to-speech technologies, speech recognition applications, and generative AI platforms, provide opportunities to modify learning environments according to individual learners' needs. These technologies may reduce unnecessary cognitive demands, provide immediate feedback, facilitate access to linguistic information, and support learners' self-regulation during reading activities (Holmes et al., 2019; Luckin et al., 2016; Wang et al., 2024). Nevertheless, a significant theoretical gap remains regarding how AI-supported learning environments may be understood within established cognitive frameworks, particularly in relation to working memory functioning among students with dyslexia.

The present paper addresses this gap by proposing a conceptual framework that positions artificial intelligence as a dynamic cognitive support system that interacts with and extends the functional capacity of working memory during reading. Rather than viewing AI merely as an external technological aid, this framework suggests that AI can redistribute cognitive demands by supporting specific components of working memory. For example, text-to-speech applications may reduce the burden placed on the phonological loop, adaptive AI guidance may support central executive functions such as attention regulation and strategy selection, visual AI-based representations may facilitate visuospatial processing, and generative AI systems may contribute to the integration of information through episodic representations.

This perspective represents a shift from considering AI as a replacement for human cognitive processes toward understanding it as a cognitive partner that enables learners with dyslexia to engage more effectively with reading tasks. Such an approach aligns with contemporary perspectives in educational psychology that emphasize the interaction between learners, cognitive resources, and learning environments (Kirschner et al., 2018; Mayer, 2021).

Therefore, the purpose of this paper is to develop a theoretically grounded framework that integrates Baddeley's working memory model with emerging AI-supported educational practices in the context of dyslexia. Specifically, the paper aims to (1) examine the potential relationship between working memory components and AI-supported reading processes; (2) conceptualize AI as a cognitive scaffold that may reduce reading-related cognitive load; and (3) provide theoretical directions for future empirical research and instructional design in educational and inclusive learning contexts.

By integrating cognitive theory with technological innovation, this paper contributes to the growing field of AI in education by offering a new perspective on how emerging technologies can be designed and implemented to support the cognitive needs of students with dyslexia.

The remainder of the paper is organized as follows. Section 2 presents the theoretical background and literature review, including dyslexia, working memory, recent research on AI and learning disabilities, cognitive load theory, and the distinction between dyslexia and special education. Section 3 presents the proposed AI–Working Memory Framework, operationalizes its four components through examples of educational activities, and formulates theoretical propositions and boundary conditions that can be examined empirically. Section 4 discusses implications for educational practice, Universal Design for Learning (UDL), teacher preparation, ethics, and an integrated empirical agenda that combines limitations and future research. Section 5 discusses the theoretical contribution of the framework, particularly its relationship to distributed cognition and competing perspectives, and Section 6 concludes the paper.

2. Theoretical Background and Literature Review

2.1 Dyslexia as a Cognitive Learning Disability

Dyslexia is a complex neurodevelopmental learning disability characterized by persistent difficulties in accurate and fluent word recognition, decoding, spelling, and reading comprehension. Although dyslexia has traditionally been associated with phonological processing deficits, contemporary research emphasizes that reading difficulties emerge from the interaction between multiple cognitive processes, including attention, executive functioning, processing speed, and working memory capacity (Pennington, 2006; Snowling & Hulme, 2021).

Reading is a cognitively demanding activity that requires the simultaneous coordination of several processes. Successful reading involves the identification of written symbols, activation of phonological representations, retrieval of semantic knowledge, monitoring of comprehension, and integration of new information with existing knowledge structures. For learners with dyslexia, inefficiencies in these processes may increase cognitive demands and

reduce the availability of mental resources required for constructing meaning from text (Swanson & Alloway, 2012).

A growing body of evidence suggests that working memory limitations represent one of the important cognitive factors contributing to reading difficulties among students with dyslexia. Unlike simple information storage, working memory involves the active manipulation and integration of information during complex cognitive tasks. Consequently, weaknesses in working memory may influence not only decoding processes but also comprehension, learning strategies, and independent engagement with texts (Peng & Fuchs, 2016).

From this perspective, supporting students with dyslexia requires approaches that extend beyond remediation of specific reading skills and consider ways to optimize the cognitive conditions under which reading occurs. This understanding provides a foundation for exploring how emerging technologies, particularly artificial intelligence, may function as cognitive supports within learning environments.

It is important to distinguish dyslexia from special education. Dyslexia refers to a specific pattern of reading and language-related difficulty, whereas special education describes educational services and settings designed to address diverse learning needs. Students with dyslexia may receive special education services in some educational systems, but dyslexia and special education are not synonymous. This distinction is important when considering AI-supported learning because the proposed framework is directed toward learners with dyslexia regardless of whether they are educated in special or inclusive settings.

2.2 Working Memory and Reading Processes: The Contribution of Baddeley's Model

Working memory is a limited-capacity cognitive system that allows information to be temporarily maintained and actively processed while a learner performs a complex task. In reading, working memory is involved in holding sound sequences, processing written symbols, directing attention, integrating information across sentences, and connecting new information with prior knowledge. Thus, working memory is not simply a short-term storage system; it supports the active coordination of information needed for comprehension and learning (Baddeley, 2000, 2012; Swanson & Alloway, 2012).

Baddeley's multicomponent model of working memory provides one of the most influential theoretical frameworks for understanding the relationship between cognitive processing and learning. According to this model, working memory is composed of four interacting components: the phonological loop, visuospatial sketchpad, central executive, and episodic buffer (Baddeley, 2000, 2012).

The phonological loop is responsible for the temporary storage and rehearsal of verbal and auditory information. In reading, this component plays a central role in phonological decoding, maintaining sound sequences, and establishing connections between graphemes and phonemes. Students with dyslexia often demonstrate reduced efficiency in phonological working memory, which may affect their ability to decode unfamiliar words and maintain accurate word representations.

The visuospatial sketchpad supports the temporary representation and manipulation of visual information. During reading, this component contributes to the processing of orthographic patterns, visual organization of text, and the recognition of written symbols. Difficulties in managing visual information may increase the cognitive effort required for reading tasks.

The central executive functions as a supervisory system responsible for attention allocation, cognitive control, planning, monitoring, and coordination between different cognitive processes. In students with dyslexia, challenges in executive control may influence their ability to regulate attention, apply reading strategies, and monitor comprehension.

The episodic buffer integrates information from different sources and connects current information with long-term memory representations. During reading comprehension, this component enables learners to construct meaningful interpretations by combining linguistic information, prior knowledge, and contextual cues.

The importance of Baddeley's framework lies in its ability to explain reading difficulties not as isolated deficits but as challenges emerging from the interaction among multiple cognitive systems. Therefore, interventions designed for students with dyslexia may benefit from approaches that provide targeted support for specific working memory processes.

The integration of artificial intelligence into educational contexts introduces the possibility of developing adaptive environments capable of providing such targeted cognitive support.

Figure 1. Baddeley's multicomponent working memory model as applied to reading.

Component	**Core function**	**Relevance to reading**
Phonological loop	Temporary storage and rehearsal of verbal/auditory information	Phonological decoding, sound sequences, grapheme–phoneme mapping
Visuospatial sketchpad	Temporary representation and manipulation of visual information	Orthographic patterns, visual organization, written symbols
Central executive	Attention, planning, monitoring, cognitive control, coordination	Strategy selection, attention regulation, comprehension monitoring
Episodic buffer	Integration of information and links with long-term memory	Construction of coherent meaning and integration of prior knowledge

Figure 1 provides a functional interpretation of the four components for reading rather than suggesting that each reading process is localized to a single component. The model is useful because it organizes cognitive demands that may become especially salient during reading; however, Baddeley's model by itself does not specify how digital technologies should be designed to interact with those processes. The proposed framework addresses this gap by connecting cognitive functions with specific AI affordances.

2.3 Literature Review: Artificial Intelligence and Dyslexia

Recent literature indicates that AI research for learners with learning disabilities is growing, but the evidence base remains uneven. Panjwani-Charania and Zhai (2024) reviewed 16 studies on AI for students with learning disabilities; 10 focused on dyslexia, while only half of the reviewed studies focused on school-age children. The review identified several AI applications, including adaptive learning, chat-based systems, intelligent tutoring, and interactive technologies, but also demonstrated that the literature is still relatively small and heterogeneous.

A more recent systematic review by Ulaş et al. (2025) examined 30 studies published between 2015 and 2025 concerning AI and innovative educational technologies for learners with learning disabilities. The review reported promising findings for reading and writing and highlighted the need for teacher training, systematic policies, and ethical standards. These findings support the potential of AI while also indicating that positive outcomes cannot be assumed simply from the presence of advanced technology.

At a broader level, Shahini et al. (2025) reviewed 84 studies of AI-driven assistive technologies for children with neurodevelopmental disorders published between 2018 and 2024. Dyslexia represented a relatively small proportion of this literature, and the authors emphasized implementation challenges, privacy, longitudinal assessment, and the continuing importance of human oversight. Similarly, Voultsiou and Moussiades (2025), reviewing 139 studies across AI, VR, and LLM applications in special education, identified opportunities for personalized learning while emphasizing ethical, accessibility, resource, and implementation challenges.

The recent literature therefore reveals three gaps that are directly relevant to the present framework. First, many studies describe what AI tools do without specifying which cognitive processes they are intended to support. Second, the relationship between AI functions, working memory, and reading development remains theoretically underdeveloped. Third, the evidence base includes heterogeneous interventions and contexts, making it difficult to determine when AI support is beneficial, for whom, and under what instructional conditions. The present framework addresses these gaps by mapping AI functions to working memory components and by formulating propositions that can be tested empirically rather than treating AI effectiveness as a general assumption.

Research on AI in education also indicates that the field has expanded rapidly while theoretical grounding and contextual implementation remain variable (Wang et al., 2024; Mustafa et al., 2024). This reinforces the need for frameworks that connect technological affordances with learning mechanisms rather than focusing only on technological capability.

2.4 Artificial Intelligence in Education: From Assistive Technology to Cognitive Partnership

Artificial intelligence has become increasingly influential in education by enabling personalized learning environments, adaptive feedback systems, automated assessment, and intelligent tutoring applications. In special education, AI-based technologies offer new

possibilities for addressing individual differences and reducing barriers experienced by learners with disabilities (Holmes et al., 2019; Luckin et al., 2016; Wang et al., 2024).

For students with dyslexia, AI applications may provide multiple forms of support. Text-to-speech technologies can transform written language into auditory information, allowing learners to access content without relying exclusively on decoding skills. Speech recognition systems may facilitate written expression by reducing the demands associated with spelling and transcription. Adaptive learning platforms can modify task difficulty, provide individualized practice, and offer immediate feedback according to learners' performance.

However, much of the existing discussion surrounding AI in dyslexia has focused on accessibility and compensation. Although this perspective is valuable, it provides only a partial understanding of the potential role of AI. A deeper theoretical perspective is needed to explain how AI may interact with cognitive processes underlying learning.

This paper proposes that AI should not be viewed solely as an assistive tool but as a dynamic cognitive partner that can support, extend, and redistribute cognitive demands during learning activities. Similar to cognitive scaffolding provided by teachers or learning environments, AI systems may temporarily support cognitive processes that are overloaded, allowing students to devote greater resources to higher-level thinking and comprehension.

Such a perspective creates a bridge between cognitive psychology and educational technology and provides a theoretical foundation for designing AI-supported interventions specifically aligned with the cognitive characteristics of learners with dyslexia.

The term "cognitive partner" in this paper does not imply that AI should replace independent cognitive activity. Instead, partnership refers to a temporary, adaptive, and pedagogically mediated redistribution of cognitive demands. This distinction is essential because continuous answer provision, excessive prompting, inaccurate explanations, or poorly timed support may create dependency or reduce opportunities for learners to practice independent strategies. The proposed framework therefore treats fading, learner agency, teacher mediation, and verification as boundary conditions rather than optional additions.

2.5 Cognitive Load Theory and AI-Supported Reading

Cognitive Load Theory provides an additional theoretical perspective for understanding the potential contribution of AI in supporting students with dyslexia. According to this theory, learning is influenced by the limited capacity of working memory, and instructional approaches should aim to reduce unnecessary cognitive demands while promoting meaningful cognitive engagement (Sweller et al., 2019).

Students with dyslexia often experience increased cognitive load during reading because substantial mental resources are allocated to basic processes such as decoding and word recognition. As a result, fewer resources remain available for comprehension, interpretation, and knowledge construction.

AI-supported learning environments may reduce extraneous cognitive load by providing immediate assistance, multimodal representations, adaptive explanations, and personalized

guidance. When aligned with learners' cognitive needs, AI may function as an external support mechanism that enables more efficient use of working memory resources.

Therefore, integrating Cognitive Load Theory with Baddeley's working memory model offers a comprehensive explanation of how AI may facilitate reading development among students with dyslexia. While working memory theory explains which cognitive processes require support, Cognitive Load Theory explains why reducing unnecessary demands may enhance learning outcomes.

Together, these perspectives provide the theoretical foundation for the proposed AI–Working Memory Framework presented in the following section.

The framework therefore treats cognitive load as a potential mechanism, not an automatic outcome. AI may reduce extraneous demands when it removes barriers that are not central to the learning goal, but AI may also introduce extraneous load through excessive information, distracting interfaces, inaccurate feedback, or unnecessary interaction. This dual possibility is important when establishing the boundary conditions of the proposed model (Sweller et al., 2019; Mayer, 2021).

3. The Proposed AI–Working Memory Framework: Artificial Intelligence as a Dynamic Cognitive Partner in Reading Development

The integration of artificial intelligence with cognitive theories of learning provides an opportunity to reconsider how technological tools may support students with dyslexia. Rather than conceptualizing AI as an external assistive device that simply compensates for reading difficulties, the present framework proposes that AI may function as a dynamic cognitive partner that interacts with the components of working memory and supports the allocation of cognitive resources during reading activities.

The central assumption underlying this framework is that reading difficulties among students with dyslexia are not solely the result of deficits in specific skills but are also associated with increased cognitive demands placed on limited working memory resources. When cognitive resources are heavily occupied by decoding, word recognition, or maintaining linguistic information, fewer resources remain available for comprehension, reasoning, and integration of meaning. Therefore, effective technological support should not only provide access to information but should also reduce cognitive overload and enhance the efficiency of cognitive processing.

Within this framework, artificial intelligence is conceptualized as an adaptive cognitive scaffold that can provide individualized support according to learners' cognitive needs. By interacting with different components of Baddeley's working memory model, AI technologies may facilitate reading processes through four complementary pathways: supporting phonological processing, enhancing visual representation, strengthening executive regulation, and facilitating information integration.

Operationally, the framework follows a four-step cycle: (1) identify the cognitive demand that is interfering with the reading goal; (2) select an AI affordance aligned with that demand; (3)

provide targeted support while preserving meaningful learner processing; and (4) evaluate both the reading outcome and the learner's ability to perform the strategy with reduced support. This sequence distinguishes cognitively aligned support from generic technology use.

3.1 AI Support for the Phonological Loop: Reducing Phonological Processing Demands

The phonological loop plays a fundamental role in maintaining and manipulating verbal information during reading. For students with dyslexia, weaknesses in phonological processing may create significant challenges in decoding unfamiliar words, maintaining sound sequences, and establishing accurate connections between written and spoken language.

AI-based technologies such as text-to-speech systems, intelligent reading assistants, and speech-based applications may provide external phonological support by transforming written information into auditory representations. This externalization of phonological information may reduce the cognitive effort required for decoding and allow learners to focus more attention on comprehension and meaning construction.

In this sense, AI does not replace the learner's phonological processing abilities; rather, it provides temporary support that enables more efficient engagement with written language. Similar to cognitive scaffolding provided by educators, AI may reduce the immediate demands placed on the phonological loop while learners gradually develop independent reading strategies.

A practical activity could involve presenting a short list of unfamiliar words embedded in a meaningful passage. The learner first attempts decoding, then uses text-to-speech or speech feedback for selected words, and finally rereads the passage with reduced assistance. The teacher can compare decoding accuracy, reading fluency, and comprehension across the supported and reduced-support phases. The purpose is not to remove phonological practice, but to reduce unnecessary immediate demands while preserving opportunities to develop decoding skills.

3.2 AI Support for the Visuospatial Sketchpad: Enhancing Visual Processing and Text Representation

The visuospatial sketchpad contributes to the processing and organization of visual information, including the recognition of written symbols, spatial organization of text, and construction of visual representations. Students with dyslexia may experience difficulties managing complex visual information, particularly when reading lengthy texts or navigating unfamiliar formats.

AI-supported visual tools, including intelligent highlighting systems, visual organizers, adaptive text formatting, and multimodal representations, may facilitate the organization of written information and reduce unnecessary visual demands. By adapting the presentation of information according to individual learners' needs, AI systems may support more efficient visual processing.

For example, AI applications may identify key concepts within a text, provide structured visual summaries, or adjust the complexity and organization of written material. Such support may allow students to allocate greater cognitive resources toward understanding relationships among ideas rather than managing the visual complexity of the text itself.

For example, after reading a short informational passage, an AI-supported environment could highlight key concepts and organize them into a simple visual map. The learner would then reconstruct the relationships among the concepts without the visual aid. Outcomes could include identification of main ideas, organization of information, and comprehension. This activity operationalizes visual support as a scaffold rather than as a substitute for the learner's own representation of the text.

3.3 AI Support for the Central Executive: Promoting Cognitive Regulation and Strategic Reading

The central executive represents the supervisory component of working memory responsible for attention regulation, planning, monitoring, and coordination of cognitive activities. These executive processes are particularly important in reading comprehension because successful readers must continuously monitor understanding, select appropriate strategies, and regulate their attention.

Students with dyslexia may experience difficulties with strategic reading behaviors, including identifying important information, maintaining focus, and recognizing comprehension breakdowns. AI-supported adaptive learning environments may provide personalized guidance, immediate feedback, and strategy prompts that assist learners in regulating their cognitive activity.

Generative AI systems, for example, may support learners by providing explanations, asking reflective questions, offering summaries, and guiding students through problem-solving processes. When appropriately designed, such systems may function as external executive supports that assist learners in organizing their cognitive efforts.

Importantly, the role of AI is not to replace executive functioning but to provide structured support that gradually encourages learner independence and metacognitive awareness.

Recent reviews emphasize that AI-supported educational systems can provide personalization and feedback, but also show that effective implementation depends on pedagogical design, teacher preparation, and responsible use (Ulaş et al., 2025; Aljemely, 2024). For the central executive, the relevant design principle is therefore not simply "more feedback," but feedback that prompts learners to plan, monitor, and evaluate their own reading.

A practical activity could ask the learner to read a short text and identify the main idea, select a strategy for an unfamiliar section, and explain why the strategy was chosen. AI can provide one reflective prompt at a time—for example, asking what information is most important or whether the learner's interpretation is supported by the text—rather than supplying the answer. After repeated practice, prompts can be faded. Measures could include strategy

selection, comprehension-monitoring accuracy, and independent performance after the AI support is removed.

3.4 AI Support for the Episodic Buffer: Facilitating Integration and Meaning Construction

The episodic buffer enables the integration of information from multiple sources and connects new information with existing knowledge stored in long-term memory. This process is essential for reading comprehension because understanding a text requires the integration of vocabulary, background knowledge, contextual information, and personal experiences.

Students with dyslexia may encounter difficulties constructing coherent representations of texts due to challenges in integrating multiple types of information simultaneously. AI technologies, particularly generative AI applications, may support this process by providing explanations, connecting concepts, generating examples, and presenting information through multiple modalities.

Through these functions, AI may facilitate the construction of meaningful learning experiences by helping students organize fragmented information into coherent conceptual structures. This process may be particularly valuable for learners who require additional support in connecting linguistic information with prior knowledge.

For example, following a reading passage, an AI system could ask the learner to connect two ideas from the text with prior knowledge and then generate a short example. The learner would verify whether the example is consistent with the text and explain the connection independently. Because generative AI can produce inaccurate or misleading content, teacher verification and source checking are necessary when AI is used for knowledge integration (UNESCO, 2023).

3.5 Theoretical Propositions: AI as Cognitive Extension Rather Than Cognitive Replacement

The proposed framework advances a theoretical proposition: artificial intelligence should be understood as a form of cognitive extension that complements human cognitive capacities rather than replacing them.

This perspective is consistent with contemporary theories of distributed cognition, which emphasize that cognitive processes are not limited to the individual mind but may emerge through interactions between individuals, tools, and learning environments (Hutchins, 1995). From this viewpoint, AI-supported learning represents an expanded cognitive environment in which technological resources can temporarily support cognitive processes that exceed learners' current capacities.

For students with dyslexia, this perspective is particularly important because it shifts the focus from remediation of deficits toward the creation of supportive cognitive environments. Rather than asking how technology can compensate for students' limitations, the framework asks how technology can enable learners to engage more effectively with complex cognitive activities.

The framework advances the following theoretical propositions. These propositions are conceptual claims derived from the integration of working memory, cognitive load, distributed cognition, and current AI literature; they are not empirical findings and require direct testing.

Proposition 1: AI support that is explicitly aligned with a learner's identified working memory demand will be more beneficial for the targeted reading process than AI support that is not cognitively aligned.

Proposition 2: AI support that reduces extraneous cognitive demands while preserving meaningful learner processing will be more likely to support comprehension than support that simply supplies answers.

Proposition 3: AI systems that provide metacognitive prompts and gradually fade assistance will be more likely to support independent strategy use than systems that provide continuous answer-based assistance.

Proposition 4: The effects of AI support will be moderated by individual differences in working memory, phonological processing, reading proficiency, and prior experience with digital tools.

Proposition 5: Excessive, poorly timed, distracting, or inaccurate AI support may increase extraneous cognitive load and weaken learner independence rather than improve learning.

Proposition 6: Teacher mediation, verification, and pedagogical alignment will strengthen the relationship between AI-supported cognitive scaffolding and reading outcomes.

These propositions establish explicit boundary conditions for the framework. AI is not assumed to be beneficial simply because it is adaptive or intelligent; its value depends on the match between the cognitive demand, the learning goal, the timing and amount of support, the accuracy of the system, and the degree to which learners remain cognitively active.

3.6 Conceptual Model Summary

The proposed AI–Working Memory Framework maps four working memory components onto specific AI-supported functions and reading-development outcomes.

Working memory component	**Reading-related demand**	**AI support**	**Targeted outcome**
Phonological loop	Decoding and maintaining sound sequences	Text-to-speech, speech feedback, auditory support	Decoding accuracy and fluency
Visuospatial sketchpad	Organizing written and visual information	Adaptive formatting, highlighting, visual organizers	Information organization and comprehension

Central executive	Attention, planning, monitoring, strategy selection	Metacognitive prompts, adaptive feedback, guided questioning	Strategic reading and self-regulation
Episodic buffer	Integrating text, context, and prior knowledge	Explanations, examples, multimodal connections	Meaning construction and comprehension

Figure 2. AI–Working Memory Framework for Supporting Reading Development in Students with Dyslexia.

Artificial Intelligence
Dynamic Cognitive Partner / Cognitive Scaffold
Working Memory Components
Phonological Loop | Visuospatial Sketchpad | Central Executive | Episodic Buffer
Targeted AI affordances aligned with cognitive demands
Reduced extraneous cognitive load + preserved learner processing
Improved cognitive accessibility during reading
Potential outcomes: decoding accuracy, reading fluency, comprehension, self-regulated learning, learner independence

Figure 2 summarizes the proposed causal logic. AI functions are not treated as direct causes of improved reading; rather, they are theorized to influence reading through targeted support of cognitive processes under specified instructional conditions. The model therefore moves from technology to cognition, from compensation to cognitive extension, and from universal technology use to personalized cognitive support.

4. Educational Implications and Future Directions

4.1 Implications for Educational Practice

The proposed AI–Working Memory Framework has important implications for special education practice. Traditionally, interventions for students with dyslexia have focused primarily on strengthening deficient skills through explicit instruction and structured practice. While these approaches remain essential, the present framework suggests that educational support should also consider the cognitive demands imposed on learners during reading activities.

From this perspective, artificial intelligence may serve as an additional layer of cognitive support that complements evidence-based instructional practices. The purpose of AI integration should not be to replace systematic literacy instruction, teacher expertise, or

human interaction. Rather, AI should be incorporated as a supportive learning environment that enables students to access texts, regulate their learning processes, and engage more independently with reading tasks.

For special education teachers, understanding the relationship between AI and working memory components may provide a theoretical basis for selecting appropriate technological tools. Instead of choosing AI applications based solely on technological availability, educators may consider the specific cognitive processes that require support.

For example, when a student demonstrates difficulties with phonological decoding, AI-based auditory support may reduce the immediate cognitive burden associated with word recognition. When the primary challenge involves maintaining attention and monitoring comprehension, adaptive AI systems may provide structured prompts and feedback that support executive functioning. Such alignment between learners' cognitive profiles and technological affordances may increase the educational value of AI applications.

The framework is intended for use across inclusive and specialized educational contexts. Its focus is the learner's reading and cognitive profile rather than the administrative label of the educational setting. Educators should therefore begin with assessment of the reading task and cognitive demand, select the least intrusive effective support, monitor whether the support is improving the intended process, and reduce support when the learner can perform independently.

4.2 Supporting Personalized and Adaptive Learning Environments Through UDL

One of the major contributions of artificial intelligence in education is its capacity to support personalized learning. Students with dyslexia represent a highly diverse population, with different cognitive profiles, learning histories, strengths, and challenges. Therefore, effective intervention requires flexible approaches that can adapt to individual needs.

The proposed framework emphasizes that personalization should extend beyond adjusting task difficulty or providing additional practice opportunities. A deeper level of personalization involves identifying which cognitive processes create barriers for individual learners and providing targeted support accordingly.

AI-driven systems have the potential to analyze learner interactions, identify patterns of difficulty, and provide adaptive assistance in real time. Such systems may adjust the presentation of information, modify instructional pathways, or provide alternative representations of content according to learners' cognitive requirements.

This approach aligns with principles of Universal Design for Learning (UDL), which emphasize the importance of providing multiple means of engagement, representation, and expression to accommodate learner variability (Meyer et al., 2014; CAST, 2024). Through AI-supported personalization, learning environments may become more responsive to the diverse cognitive needs of students with dyslexia.

UDL provides a complementary perspective because it begins from learner variability rather than from a single "typical" learner. CAST's UDL Guidelines 3.0 organize design around

multiple means of engagement, representation, and action and expression, with an emphasis on learner agency, accessible materials, strategy development, and graduated support (CAST, 2024). In an AI-supported reading environment, multiple means of engagement may include meaningful choice and appropriately calibrated challenge; multiple means of representation may include text, audio, visual organization, and explanations; and multiple means of action and expression may allow learners to respond through speech, writing, or other accessible formats. For students with dyslexia, these principles can be linked to the proposed working-memory framework by selecting representations and supports according to the cognitive demands of a specific reading task.

UDL should not be interpreted as evidence that every learner needs every option. Rather, the framework supports purposeful selection of options and graduated assistance. This is also consistent with a critical perspective on UDL evidence: design recommendations should be treated as pedagogical principles that require context-sensitive empirical evaluation rather than as guarantees of improved learning (Boysen, 2024).

4.3 Implications for Teacher Training and Professional Development

Although AI technologies offer promising opportunities, their educational effectiveness depends largely on teachers' knowledge, beliefs, and ability to integrate them meaningfully into instruction. Therefore, professional development in special education should include not only technical training but also theoretical understanding of how AI interacts with cognitive processes.

Teachers need opportunities to develop what may be described as cognitive-technological pedagogical knowledge: the ability to understand learners' cognitive characteristics, evaluate technological affordances, and design instructional experiences that connect both domains.

Without such understanding, AI implementation may remain superficial, with technologies being used as additional tools without clear pedagogical purposes. In contrast, teachers who understand the relationship between working memory and AI-supported learning can make informed decisions regarding when, why, and how technology should be integrated.

Thus, teacher preparation programs and professional development initiatives should address three interconnected dimensions:

Cognitive knowledge – understanding learning processes and cognitive challenges associated with dyslexia.

Technological knowledge – understanding the possibilities and limitations of AI-based educational tools.

Pedagogical knowledge – applying AI within evidence-based instructional approaches.

Recent reviews of teacher-focused AI research similarly identify a need for stronger professional development, ethical awareness, and pedagogical guidance rather than technology training alone (Aljemely, 2024). Teacher preparation should therefore include opportunities to analyze AI outputs, recognize inaccurate or biased responses, select

cognitively appropriate supports, plan fading of assistance, and monitor whether students remain active participants in learning.

4.4 Ethical Considerations and Responsible Use of AI in Dyslexia Support

Despite its potential benefits, the integration of AI in special education requires careful consideration of ethical issues. Students with learning disabilities represent a vulnerable population, and technological innovation must be guided by principles of responsibility, accessibility, and educational equity.

First, AI-supported systems should preserve the central role of educators and avoid creating dependence on technology. The goal of AI integration should be to empower learners and enhance independence rather than replace human guidance.

Second, issues related to data privacy, algorithmic transparency, and equitable access require careful attention. AI systems often rely on collecting and analyzing learner data; therefore, educational institutions must ensure that such data are used responsibly and that students' rights are protected.

Third, AI applications should be evaluated not only according to technological performance but also according to their educational and cognitive value. A technologically advanced system is not necessarily beneficial if it does not address learners' actual cognitive and educational needs.

Consequently, responsible AI implementation requires collaboration among researchers, educators, technology developers, families, and policymakers.

These considerations are consistent with UNESCO's human-centered guidance, which emphasizes privacy, age-appropriate use, pedagogical validation, equity, and human agency in educational applications of generative AI (UNESCO, 2023). For learners with dyslexia, ethical use also requires avoiding assumptions that AI output is accurate, ensuring that accessibility tools do not become barriers to independent learning, and preserving meaningful opportunities for students to read, reason, and communicate without technological mediation.

4.5 Integrated Research Directions, Limitations, and Empirical Agenda

As a conceptual paper, the present framework does not provide empirical evidence regarding the effectiveness of specific AI interventions. Its propositions therefore remain theoretical. The principal limitation is that the proposed relationship between AI-supported cognitive scaffolding, working memory processes, and reading outcomes has not yet been tested directly. In addition, students with dyslexia are heterogeneous, and differences in phonological processing, working memory, reading proficiency, language, age, motivation, and prior technology experience may moderate effects. Contextual factors such as teacher expertise, access to technology, school resources, language characteristics, privacy requirements, and cultural expectations may also influence implementation.

An empirical agenda should test the framework through studies that compare cognitively aligned AI support with non-aligned AI support and with evidence-based instruction without

AI. Outcome measures should include decoding accuracy, reading fluency, comprehension, working memory performance, cognitive load, metacognitive strategy use, and independent performance after support is withdrawn. Experimental and mixed-methods designs could be complemented by qualitative analyses of learner and teacher experiences. Longitudinal studies are particularly important because immediate performance gains do not necessarily demonstrate durable changes in reading development or independence.

Future studies should also examine learner profiles and responsiveness. For example, researchers could test whether learners with greater phonological processing difficulties benefit more from auditory support, whether learners with executive regulation difficulties benefit more from metacognitive prompts, and whether multimodal support is most useful when integration demands are high. Research should additionally examine the effects of inaccurate AI responses, excessive prompting, and different levels of assistance in order to test the dependency and cognitive-load boundary conditions proposed in this paper.

Finally, AI tools should be designed and evaluated as theoretically informed educational systems. Rather than asking only whether a tool improves a reading score, future research should examine whether the tool supports the intended cognitive mechanism, whether the effect transfers when the tool is removed, and whether the learner becomes more independent over time. This approach would allow the field to move from demonstrations of technological possibility toward evidence-based cognitive design.

5. Discussion

The proposed framework responds to a central challenge in current AI-supported education: technological capabilities are developing rapidly, while theoretical explanations of how AI influences specific learning processes remain less developed. By integrating Baddeley's working memory model with cognitive load theory, distributed cognition, UDL, and recent AI literature, the framework shifts the question from whether AI improves reading to how, when, and for whom particular AI functions may support reading-related cognitive processes. This shift is important because recent reviews demonstrate both promising applications and substantial heterogeneity, implementation challenges, and limitations in the current evidence base (Panjwani-Charania & Zhai, 2024; Shahini et al., 2025; Ulaş et al., 2025; Voultsiou & Moussiades, 2025).

5.1 Distributed Cognition and the Meaning of Cognitive Partnership

The concept of distributed cognition provides a useful theoretical explanation for the term "cognitive partner." Distributed cognition emphasizes that cognitive activity can emerge through interactions among people, tools, representations, and environments (Hutchins, 1995). Applied to dyslexia support, AI may become part of the learning environment by externalizing information, providing temporary prompts, transforming written language into auditory input, or helping organize relationships among ideas. The important point is that the cognitive system is not being transferred from learner to machine. Instead, selected demands are redistributed across the learner, teacher, AI system, and instructional environment. This interpretation also clarifies why AI dependence is a boundary condition: if the learner cannot

perform the targeted strategy when AI support is removed, the system may be functioning as replacement rather than cognitive extension.

5.2 Theoretical Contribution and Boundary Conditions

The framework extends existing scholarship by bringing several perspectives into a defined relationship rather than simply listing them. Baddeley's model identifies candidate cognitive processes for support; Cognitive Load Theory explains why reducing unnecessary demands may help while also warning that poorly designed support can create additional load; distributed cognition explains how tools can participate in cognitive activity; UDL emphasizes learner variability, accessibility, and agency; and human-centered AI guidance emphasizes privacy, equity, pedagogical validation, and human oversight (Sweller et al., 2019; CAST, 2024; UNESCO, 2023). The resulting framework is bounded by five conditions: cognitive alignment, preservation of meaningful learner processing, appropriate timing and fading of support, teacher mediation and verification, and attention to individual and contextual differences. These conditions distinguish the proposed model from a general claim that AI is inherently beneficial.

5.3 Implications for Research and Practice

The framework has practical value because it gives educators a rationale for selecting AI functions according to cognitive and reading needs, while giving researchers measurable propositions about mechanisms, moderators, and outcomes. It also provides a basis for evaluating whether AI support transfers to independent performance. In this sense, the theoretical contribution is not the claim that AI improves reading, but the proposal that AI-supported reading should be designed and evaluated according to identifiable cognitive functions and explicit boundary conditions.

6. Conclusion

Artificial intelligence creates new possibilities for personalization, accessibility, and learner support, but its educational value depends on how it is integrated with cognitive and pedagogical principles. This paper proposed the AI–Working Memory Framework, which conceptualizes AI as a dynamic cognitive partner that can temporarily support and redistribute selected cognitive demands during reading among students with dyslexia.

By mapping AI functions onto the phonological loop, visuospatial sketchpad, central executive, and episodic buffer, the framework provides a theoretical explanation for how different forms of support may contribute to decoding, visual organization, strategic regulation, and meaning construction. The framework also establishes explicit propositions and boundary conditions concerning cognitive alignment, cognitive load, learner independence, individual differences, and teacher mediation.

The model is conceptual and therefore does not establish empirical effectiveness. Its contribution is to provide a testable structure for future research and a practical basis for designing cognitively meaningful AI-supported reading environments. Future studies should determine whether targeted AI support produces durable improvements in reading and

cognitive processes and whether learners retain the relevant strategies when technological assistance is reduced or removed. A human-centered, theoretically grounded approach is therefore essential if AI is to expand learning opportunities without replacing the cognitive and relational dimensions of education.

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