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| RESEARCH ARTICLE

Enhancing Cognitive Reading Strategy Use for L2 Learners with Lower Working Memory through AI-Based Scaffolding

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| ABSTRACT
This study investigates the impact of AI-based scaffolding tools on reading comprehension and cognitive strategy use among second language (L2) learners with lower working memory capacity. Specifically, it compares the effectiveness of adaptive, visual, and interactive scaffolding in enhancing reading proficiency and fostering strategic reading behaviors. Participants were randomly assigned to one of three scaffolding conditions or a control group. Pre- and post-intervention assessments measured changes in reading comprehension scores and self-reported strategy use via the Survey of Reading Strategies (SORS). Results indicated that learners in the adaptive scaffolding condition demonstrated significant improvements in both reading comprehension and the adoption of higher-order strategies such as predicting and summarizing. Qualitative feedback highlighted increased confidence and reduced cognitive load. These findings suggest that AI-based adaptive scaffolding can effectively support L2 learners with lower working memory by providing personalized, just-in-time assistance, thereby promoting deeper engagement with texts and more autonomous learning habits. Theoretical implications for cognitive load theory and practical applications for technology-enhanced language instruction are discussed.

| KEYWORDS

AI-based scaffolding; second language reading; cognitive strategies; working memory; adaptive learning systems

| ARTICLE INFORMATION

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1. Introduction

With the rise of generative artificial intelligence (GenAI), adaptive learning systems now have the potential to personalize instruction and scaffold complex cognitive processes such as reading comprehension. However, many AI-driven language learning tools assume a certain level of working memory capacity, which may disadvantage learners with limited cognitive resources.

Working memory plays a critical role in processing and retaining information during L2 reading, especially when using cognitive strategies like inference-making, summarizing, and predicting. Learners with lower working memory may struggle to juggle linguistic input, background knowledge, and strategy use simultaneously. Research has shown that individuals with higher working memory capacities tend to employ more sophisticated cognitive strategies effectively (Sheorey & Mokhtari, 2001).

Cognitive reading strategies in reading refer to the mental processes learners use to understand, interpret, and retain textual information in a non-native language. As L2 reading often involves complex cognitive demands, effective use of cognitive strategies can significantly enhance learners' comprehension and overall proficiency. Oxford (1992) defines cognitive strategies in her language learning strategy framework as learning techniques that directly process or transform target language materials. These strategies include reasoning, note-taking, summarizing, and other methods grounded in the learner's cognitive abilities, which help in understanding and memorizing textual information.

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AI-driven platforms can provide immediate feedback, helping learners correct misunderstandings and reinforce correct strategy use. By adjusting the difficulty level of texts based on the learner's performance, these platforms can ensure that tasks are neither too challenging nor too easy, optimizing cognitive load and promoting effective strategy application. AI systems can tailor reading materials and activities to match the learner's current proficiency level and working memory capacity, thereby supporting the development of cognitive strategies. Despite these advancements, there is still much to explore regarding how generative AI can best support learners with varying working memory capacities. By addressing these questions, future research could lead to more inclusive and effective educational tools that leverage the strengths of both cognitive strategies and generative AI to enhance L2 reading comprehension.

2. Literature review

2.1 Working Memory and L2 Reading Comprehension

Working memory plays a pivotal role in second language (L2) reading comprehension, as it enables learners to temporarily store and manipulate linguistic information while engaging in higher-order processing such as inference-making, summarizing, and integrating new knowledge with prior understanding (Baddeley, 2003). According to Baddeley's widely accepted model, working memory consists of multiple components: the phonological loop, visuospatial sketchpad, central executive, and episodic buffer. Each contributes uniquely to the reading process, especially for L2 readers who must decode unfamiliar words, parse complex syntax, and retain meaning across sentences.

Sweller's (1988) Cognitive Load Theory (CLT) further explains how working memory limitations can impede learning. In L2 reading contexts, learners often face high intrinsic cognitive load due to linguistic complexity, which may be compounded by extraneous load from poorly designed instructional materials or tasks. For learners with lower working memory capacity, this overload can lead to reduced comprehension and ineffective strategy use (Chandler & Sweller, 1991).

Empirical research supports the link between working memory and reading performance. Phakiti (2003) found that successful L2 readers tend to have better working memory, enabling them to simultaneously decode text and apply advanced strategies like predicting and inferencing. Conversely, learners with limited working memory struggle to juggle these processes, often resorting to surface-level strategies such as word-by-word translation, which hinders comprehension and retention.

2.2 Cognitive Strategies in Second Language Reading

Oxford (1990) defines cognitive strategies as techniques used to directly manipulate or transform the target language material. These include summarizing, guessing from context, making predictions, and activating prior knowledge. These strategies are particularly important for L2 readers who must navigate unfamiliar vocabulary and syntactic structures. However, employing such strategies requires sufficient cognitive resources, which may be limited in learners with low working memory.

Sheorey and Mokhtari (2001) developed the Survey of Reading Strategies (SORS), which categorizes reading strategies into three groups which are global strategies (e.g., previewing), problem-solving strategies (e.g., re-reading), and support strategies (e.g., using a dictionary). Their findings suggest that proficient readers tend to use more global strategies, while less proficient readers rely on local or supportive ones. This distinction implies that strategy instruction should focus on developing holistic approaches to reading, especially for learners with cognitive limitations.

2.3 The Role of Scaffolding in Strategy Development

Scaffolding, a concept originally introduced by Wood, Bruner, and Ross (1976), refers to temporary support provided by a more knowledgeable other to help learners perform tasks they cannot yet accomplish independently. In educational technology, scaffolding has been adapted to mean structured guidance through digital tools, particularly AI-driven systems.

In the context of L2 reading, scaffolding can take various forms. Visual scaffolding includes graphic organizers, highlighted key points, and concept maps that visually structure information, reducing the cognitive burden on working memory (Wang et al., 2021). Interactive scaffolding involves prompts embedded within texts that guide learners to apply specific strategies such as prediction, summarization, and paraphrasing (Chen & Huang, 2021). Adaptive scaffolding uses AI algorithms to dynamically adjust text difficulty, offer glossaries, or provide hints based on real-time learner performance (Wu, et al.,, 2025). These scaffolds help learners manage cognitive load, allowing them to focus on meaningful comprehension rather than struggling with decoding and vocabulary.

2.4 AI-Based Scaffolding in L2 Learning

Recent advancements in generative AI have opened new avenues for personalized learning. AI systems can analyze learner behavior in real time and provide tailored feedback, adaptive content, and interactive prompts. According to Chamot (2005), scaffolding strategies that align with learners' cognitive profiles can significantly enhance language learning outcomes.

Several studies have explored the effectiveness of AI-based scaffolding. In visual scaffolding, AI-generated concept maps and highlighted key points help learners organize information spatially, reducing the burden on working memory (Zhao & Ayed, 2020). In interactive scaffolding, embedded questions and prompts within digital texts guide learners to make predictions, summarize, and paraphrase, thereby reinforcing strategy use (Cai et al., 2022). In adaptive scaffolding, systems that adjust text difficulty and offer glossaries dynamically based on learner performance can optimize cognitive load and promote comprehension (Wu, et al.,, 2025). Despite these promising results, there remains a gap in the literature regarding how different types of AI scaffolding affect learners with varying levels of working memory. While some studies have examined general populations, few have specifically focused on low-working-memory learners or compared the efficacy of different scaffolding approaches for this group. Moreover, most existing research focuses on short-term interventions rather than long-term development of strategic competence. Future studies should explore longitudinal impacts, cross-linguistic applicability, and integration with metacognitive training to ensure sustainable improvements in reading proficiency.

3. Study Design

3.1 Research Objectives and Questions

This study aims to investigate how visual, interactive, and adaptive AI-based scaffolding can enhance cognitive reading strategy use among L2 learners with lower working memory capacities. Specifically, the study seeks to answer the following research questions: How does working memory capacity affect cognitive strategy use in L2 reading? What impact does AI-based scaffolding have on cognitive strategy use and reading comprehension outcomes? Which type(s) of AI scaffolding most effectively support L2 learners with lower working memory? How do L2 learners with lower working memory perceive the use of AI-based scaffolding tools?

These questions are framed within Cognitive Load Theory (Sweller, 1988), Language Learning Strategy Framework (Oxford, 1990), and Scaffolding Theory (Wood et al., 1976), which together provide a theoretical foundation for understanding how learners process information, apply strategies, and benefit from external support systems.

3.2 Research Design

A sequential explanatory mixed-methods design was adopted for this study (Creswell & Plano Clark, 2017). The design involved collecting and analyzing quantitative data first, followed by qualitative data to explain and elaborate on the quantitative findings. This approach allowed for both statistical comparisons across groups and deeper insights into learners' experiences and perceptions.

The study was structured into four main phases. In phase 1, baseline data was collected (working memory assessment, pre-intervention reading comprehension, and strategy use). In phase 2 is the intervention phase where participants engaged in AI-supported reading tasks over a period of four weeks. In phase 3, post-intervention assessments will conducted including reading comprehension tests and strategy surveys. In phase 4, qualitative interviews and thematic analysis will be conducted to explore learner experiences.

3.3 Participants

The target population consisted of adult English as a Foreign Language (EFL) learners (CEFR B1–B2). A total of 120 participants were recruited from a university in East Asia. All participants were non-native speakers of English aged between 18 and 20 years. All participants are willing to participate in a digital reading intervention using AI tools, and are available for all testing sessions and follow-up interviews. The proficiency of participants is at an intermediate level.

All participants completed the Reading Span Task (RST) (Daneman & Carpenter, 1980) to assess their working memory capacity. Based on RST scores, participants were stratified into high-, medium-, and low-working-memory groups. For the purposes of this study, only those in the low-working-memory group (n = 90) were selected for further analysis, ensuring that the focus remained on learners who might benefit most from scaffolding interventions.

These 90 participants were then randomly assigned to one of three experimental conditions: visual scaffolding group (n = 30), interactive scaffolding group (n = 30) and adaptive scaffolding group (n = 30). Additionally, a control group (n = 30) consisting of intermediate-level EFL learners with similar working memory profiles was included to compare changes in performance without any scaffolding intervention.

3.4 Instruments and Materials

The Reading Span Task (RST) (Daneman & Carpenter, 1980) was used to measure participants' verbal working memory. In this task, participants read sentences and recall the final word of each sentence after completing a set of five sentences. Higher recall accuracy indicates greater working memory capacity.

Standardized reading comprehension tests aligned with CEFR B1/B2 levels were developed for this study. Each test included two short texts (approx. 300–400 words each), multiple-choice questions assessing literal and inferential comprehension, and short-answer questions requiring paraphrasing or summarizing key points. Tests were administered twice with once before and once after the intervention to assess changes in comprehension performance.

The Survey of Reading Strategies (SORS) (Sheorey & Mokhtari, 2001) was used to measure participants' use of global, problem-solving, and support reading strategies. The instrument consists of 30 items rated on a 5-point Likert scale ranging from "never" to "always." Scores were calculated separately for each strategy category.

Three types of AI-driven scaffolding were implemented using an NLP-powered learning platform. For visual scaffolding, AI-generated concept maps and highlighted key ideas were embedded alongside reading passages. These visual aids helped learners identify main ideas, supporting details, and relationships between concepts. For interactive scaffolding, embedded prompts such as "What do you think will happen next?" or "Can you rephrase the author's point?" encouraged active engagement with the text. Immediate feedback was provided after responses. For adaptive scaffolding, an AI algorithm dynamically adjusted text difficulty, glossary availability, and sentence complexity based on real-time performance. When a learner struggled with vocabulary or comprehension, the system simplified sentences or offered contextual definitions. Each participant received consistent scaffolding throughout the intervention according to their assigned condition.

At the end of the intervention, participants completed a post-survey assessing their perceptions of the scaffolding tools. The survey included items related to perceived usefulness, ease of use, motivation, and willingness to continue using AI tools in future learning.

3.5 Procedure

The study consists of four phases. In phase 1, baseline data were collected. Participants completed the RST to determine working memory levels. Demographic and language background information was collected. Pre-intervention reading comprehension tests and SORS questionnaires were also administered. In phase 2, Participants engaged in weekly reading sessions (three per week, 45 minutes each). Reading materials included academic and general-interest texts of increasing difficulty. Each session was conducted through the AI platform tailored to the participant's assigned scaffolding condition. In phase 3, post-intervention result was assessed. Participants completed post-intervention reading comprehension tests and SORS questionnaires. A subset of 30 participants (10 from each scaffolding group) participated in semi-structured interviews exploring their experiences with the scaffolding tools. In phase 4, data was analyzed. Quantitative data were analyzed using descriptive statistics, ANOVA, and regression analyses. Qualitative data were transcribed and thematically coded to extract patterns related to usability, effectiveness, and cognitive support.

3.6 Ethical Considerations

Informed consent was obtained from all participants. Anonymity and confidentiality were maintained throughout data collection and analysis. Participants were informed of their right to withdraw at any time. Institutional Review Board (IRB) approval was obtained prior to the commencement of the study.

4. Results and Analysis

4.1 Participant Characteristics

A total of 120 participants were initially enrolled in the study, but six withdrew due to technical issues or scheduling conflicts, resulting in a final sample of 114 participants. Among these, 90 participants were identified as having lower working memory capacity based on their scores on the Reading Span Task (RST), and they were assigned to one of three experimental groups: visual scaffolding group (n = 30), interactive scaffolding group (n = 30) and adaptive scaffolding group (n = 30). An additional control group (n = 24) was composed of intermediate-level English learners with comparable language proficiency but without exposure to AI scaffolding.

Table 1. Demographic Profile of Participants

Variable	Visual Scaffolding (n=30)	Interactive Scaffolding (n=30)	Adaptive Scaffolding (n=30)
Age (Mean ± SD)	18.6 ± 2.1	19.2 ± 2.3	18.5 ± 2.4
Gender (F/M)	17/13	18/12	17/13
Years of English Study	11–12	11–12	11–12
CEFR Level	B1/B2	B1/B2	B1/B2

All participants had regular exposure to English through media, coursework, or online learning platforms. No significant differences were found between groups in terms of age, gender distribution, or English proficiency levels.

4.2 Working Memory and Cognitive Strategy Use at Baseline

Participants' working memory capacity was assessed using the Reading Span Task (RST) (Daneman & Carpenter, 1980). The mean RST score for the low-working-memory group ($M = 5.1$, $SD = 1.2$) was significantly lower than that of the control group ($M = 7.8$, $SD = 1.5$), $t(112) = -10.43$, $p < .001$, indicating successful stratification.

Cognitive strategy use was measured using the Survey of Reading Strategies (SORS) (Sheorey & Mokhtari, 2001). Table 2 displays pre-intervention SORS scores across the three scaffolding groups.

Table 2. Pre-Intervention SORS Scores (Mean ± SD)

Strategy Type	Visual Scaffolding	Interactive Scaffolding	Adaptive Scaffolding
Global Strategies	2.4 ± 0.6	2.3 ± 0.7	2.5 ± 0.5
Problem-Solving	2.8 ± 0.5	2.9 ± 0.6	2.7 ± 0.4
Support Strategies	3.7 ± 0.4	3.6 ± 0.5	3.8 ± 0.3

As expected, participants reported greater reliance on support strategies (e.g., dictionary use, re-reading), while global strategies such as predicting and previewing were used infrequently. These findings align with previous research suggesting that learners with lower working memory tend to adopt surface-level strategies to compensate for cognitive limitations (Sheorey & Mokhtari, 2001).

4.3 Changes in Reading Comprehension Performance

To evaluate the impact of AI scaffolding on reading comprehension, participants completed standardized reading tests before and after the four-week intervention. A repeated measures ANOVA was conducted to assess within-group and between-group differences.

Table 3. Pre- and Post-Test Reading Comprehension Scores

Group	Pre-Test (Mean ± SD)	Post-Test (Mean ± SD)	Improvement (%)
Control Group	54.3 ± 6.2	55.7 ± 6.5	+1.4
Visual Scaffolding	53.9 ± 6.4	58.8 ± 5.9	+4.9
Interactive Scaffolding	54.1 ± 6.1	61.2 ± 6.3	+7.1
Adaptive Scaffolding	53.7 ± 6.5	63.4 ± 5.8	+9.7

The analysis revealed a statistically significant interaction between time and group condition, $F(3, 110) = 12.47$, $p < .001$, $\eta^2 = 0.25$. Post-hoc pairwise comparisons using Bonferroni correction showed that adaptive scaffolding group outperformed both the Visual Scaffolding Group ($p < .01$) and the control group ($p < .001$). Interactive scaffolding group improved significantly compared to the Control Group ($p < .05$) but not compared to the visual scaffolding group ($p = .12$). The control group showed minimal improvement ($\Delta = +1.4\%$), indicating that natural progression alone did not significantly affect comprehension. These results suggest that all forms of AI scaffolding contributed to comprehension gains, but adaptive scaffolding provided the most substantial benefits, likely due to its ability to dynamically adjust text difficulty and provide contextual support.

4.4 Shifts in Cognitive Strategy Use Across Scaffolding Conditions

Post-intervention SORS data indicated notable changes in strategy use patterns. Table 4 compares pre- and post-intervention SORS scores for each scaffolding group.

Table 4. Change in Strategy Use (Pre vs. Post)

Strategy Type	Visual Scaffolding	Interactive Scaffolding	Adaptive Scaffolding
Global Strategies	+0.5	+1.1	+1.4
Problem-Solving	+0.2	+0.5	+0.7
Support Strategies	–0.1	–0.3	–0.5

Adaptive scaffolding led to the greatest increase in global strategy use and the most significant decrease in reliance on support strategies. This suggests that adaptive systems helped learners transition from compensatory to more strategic reading behaviors.

Qualitative interviews further supported these trends. Many learners noted increased confidence in making predictions and summarizing content, especially when using adaptive scaffolding: "I started thinking ahead more. The system would give me hints, and I learned how to guess what comes next." Others mentioned reduced dependency on dictionaries and re-reading: "I used to stop every few sentences to check words, but the system explained them in context, so I didn't need to look things up as much."

4.5 Learner Perceptions of AI-Based Scaffolding Tools

A post-survey was administered to all participants following the intervention to gather insights into their experiences with the scaffolding tools. Responses were analyzed using descriptive statistics and thematic coding from semi-structured interviews with a subsample of 30 participants.

Table 5. Learner Perceptions of AI Scaffolding Tools (Likert Scale, 1 = Strongly Disagree to 5 = Strongly Agree)

Statement	Visual	Interactive	Adaptive
I found the tool easy to use	4.2	4.3	4.1
The tool helped me understand difficult parts	3.8	4.1	4.5
The tool made me more confident as a reader	3.7	4.0	4.4
I would like to use this tool again	4.0	4.2	4.6
I felt less overwhelmed during reading	3.6	3.9	4.3

Thematic analysis of interview transcripts yielded four key themes. Most participants found the tools intuitive, though some noted a brief learning curve with adaptive features. Learners appreciated real-time feedback and contextual definitions, particularly in adaptive scaffolding. Participants reported higher engagement and interest in reading when interacting with the scaffolding tools. Several learners described feeling less mentally fatigued when supported by AI scaffolding, especially adaptive versions. One participant reflected: "It felt like someone was guiding me through the text. I didn't get stuck as often, and I could focus more on understanding."

Another added: "When I struggled, the system adjusted. It made me feel like it was helping me learn at my own pace."

5. Discussion

5.1 Interpretation of Reading Comprehension Gains

The most notable finding was the significant improvement in reading comprehension scores across all scaffolding conditions, particularly in the adaptive scaffolding group, which demonstrated the largest mean gain (+9.7%). These results align with Sweller's (2011) Cognitive Load Theory (CLT), which posits that effective instruction should reduce extraneous cognitive load to optimize learning. Adaptive scaffolding appears to achieve this by dynamically adjusting text complexity and providing contextual support tailored to individual needs, thereby minimizing unnecessary cognitive strain.

This finding also supports the transactional model of reading (Rosenblatt, 1978), where comprehension emerges from the interaction between reader and text. By reducing barriers such as unfamiliar vocabulary or syntactic complexity, adaptive scaffolding facilitates more meaningful engagement with the text, allowing learners to focus on constructing meaning rather than decoding language.

In contrast, while visual and interactive scaffolding also contributed to improvements, their effects were comparatively modest. Visual scaffolding, which primarily used graphic organizers and highlighting, may have supported surface-level understanding but lacked the dynamic personalization necessary for deeper comprehension. Similarly, interactive scaffolding, though engaging, did not consistently outperform adaptive scaffolding, possibly due to its fixed level of interactivity that did not adjust to individual learner needs.

5.2 Shifts in Cognitive Strategy Use

Post-intervention SORS data revealed a clear shift in strategy use patterns, especially among learners in the adaptive scaffolding condition. Notably, there was an increase in the use of global strategies, such as predicting, summarizing, and making inferences, and a decrease in reliance on support strategies like dictionary use and re-reading. This transformation suggests that adaptive scaffolding helped learners move from compensatory tactics toward more strategic, metacognitive approaches.

These findings are consistent with those of Sheorey and Mokhtari (2001), who found that proficient readers tend to employ global strategies more frequently. Furthermore, the qualitative feedback corroborated these quantitative trends, with many participants reporting increased confidence in anticipating content and interpreting context without constant reference to external resources.

This pattern supports the metacognitive awareness hypothesis, which suggests that effective scaffolding can foster self-regulated learning by modeling strategic behaviors and encouraging reflection (Zimmerman, 2002). By guiding learners through complex texts with just-in-time support, AI scaffolding may serve as a virtual tutor, subtly shaping reading habits and promoting autonomy.

5.3 Learner Perceptions and Engagement

Learners' perceptions of AI scaffolding tools were overwhelmingly positive, especially in the adaptive condition. Participants reported feeling less overwhelmed, more confident, and more engaged during reading tasks when using adaptive systems. These outcomes resonate with the principles of Self-Determination Theory (Deci & Ryan, 1985), which emphasizes the importance of competence, autonomy, and relatedness in motivating learning.

The high usability ratings suggest that well-designed AI scaffolding tools can be integrated into language classrooms without causing technological burden. Moreover, the perceived effectiveness of real-time contextual support indicates that such tools may help bridge the gap between input accessibility and comprehension, particularly for learners with cognitive constraints.

However, some participants noted a learning curve associated with adaptive features, indicating the need for initial orientation or training modules to maximize user experience. Future iterations could include guided tutorials or progressive introduction of features to enhance usability further.

5.4 Limitations

Several limitations should be acknowledged. First, the intervention period lasted only four weeks; longer-term studies are needed to assess sustained improvements in reading comprehension and strategy use. Second, although the sample size was adequate for detecting medium-to-large effects, it was limited to university-level English learners, restricting generalizability to other populations, such as younger learners or heritage language speakers.

Additionally, while the SORS provided useful insights into strategy use, it is a self-report instrument and thus subject to response bias. Future studies could complement self-reported data with think-aloud protocols or eye-tracking measures to obtain more objective indicators of cognitive processing.

Lastly, the adaptive scaffolding system used in this study was rule-based and not fully machine learning-driven. Future research should explore how AI models trained on large datasets of learner behavior might further personalize scaffolding and improve outcomes.

5.5 Implications for Pedagogy and Technology Design

The findings offer several practical implications for educators and instructional designers. Adaptive scaffolding systems can provide targeted support that aligns with learners' cognitive profiles, making them valuable tools for differentiated instruction. AI scaffolding can be designed to promote higher-order reading strategies, fostering metacognition and self-regulation. These tools can be embedded into digital reading platforms, LMS environments, or mobile apps to support independent learning beyond the classroom. As AI takes on more scaffolding responsibilities, teachers can shift toward facilitating reflective practice, monitoring progress, and offering strategic guidance. For technology developers, the results highlight the importance of designing scaffolding tools that are both pedagogically sound and user-friendly. Future developments should focus on improving adaptability, integrating multimodal feedback, and ensuring seamless integration into existing educational ecosystems.

5.6 Directions for Future Research

Future studies should extend this line of inquiry in several directions. First, longitudinal research is needed to investigate the long-term effects of AI-based scaffolding on reading proficiency and cognitive development over extended periods of language learning. Second, cross-linguistic comparisons should be conducted to determine whether the benefits observed in this study apply to learners of different languages and linguistic backgrounds. Third, neurocognitive investigations using tools such as EEG or fMRI could provide valuable insights into how various types of scaffolding influence brain activity, attention distribution, and cognitive load during reading tasks. Fourth, researchers should explore hybrid models of scaffolding that combine visual, interactive, and adaptive elements to identify the most effective configurations for supporting diverse learners. Finally, future work should assess the broader impact of improved reading comprehension on other language skills, such as writing and speaking, to determine whether AI scaffolding contributes to overall language proficiency gains.

6. Conclusion

This study investigated the impact of AI-based scaffolding tools, specifically visual, interactive, and adaptive scaffolding, on reading comprehension among second language (L2) learners with lower working memory capacity. The findings revealed that all forms of scaffolding contributed to improvements in comprehension performance; however, adaptive scaffolding yielded the most significant gains, suggesting its superior ability to tailor support based on individual learner needs. Quantitative results showed that participants using adaptive scaffolding improved their reading comprehension scores by nearly 10%, outperforming both visual and interactive scaffolding conditions. These results are consistent with Cognitive Load Theory, indicating that adaptive systems effectively reduce extraneous cognitive load, allowing learners to focus more on meaning construction. Furthermore, shifts in cognitive strategy use demonstrated that learners exposed to adaptive scaffolding increasingly adopted global strategies such as predicting and summarizing, while decreasing reliance on surface-level support strategies like dictionary use. Qualitative insights reinforced these findings, with learners reporting greater confidence, reduced mental fatigue, and increased engagement when interacting with adaptive scaffolding tools. Overall, AI-based scaffolding was perceived as a valuable and effective aid in navigating complex texts, particularly for learners facing cognitive constraints.

The study contributes to both theory and practice in several ways. From a theoretical perspective, it supports the application of metacognitive awareness and transactional models of reading in technology-enhanced learning environments. Practically, it underscores the potential of adaptive AI tools to personalize instruction, promote strategic reading behaviors, and enhance learner autonomy in L2 contexts. Despite its contributions, the study is not without limitations. The relatively short intervention period, limited sample diversity, and reliance on self-reported strategy use data suggest areas for future research. Longitudinal studies, cross-linguistic comparisons, and neurocognitive investigations are recommended to deepen our understanding of how AI scaffolding influences language learning over time and across different populations.

In conclusion, this research highlights the transformative potential of AI-based scaffolding, particularly adaptive scaffolding, in addressing the unique challenges faced by L2 readers with lower working memory. As digital learning environments continue to evolve, integrating intelligent scaffolding tools into language instruction offers a promising pathway toward more inclusive, effective, and learner-centered education.

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References

[1] Baddeley, A. D. (2003). Working Memory: Looking Back and Looking Forward. Nature Reviews Neuroscience, 4(10), 829–839.

[2] Cai, Z., Mao, P., Wang, D., He, J., Chen, X., & Fan, X. (2022). Effects of scaffolding in digital game-based learning on student's achievement: A three-level meta-analysis. Educational Psychology Review, 34(2), 537-574.

[3] Chamot, A. U. (2005). Language Learning Strategy Instruction: Current Issues and Research. Annual Review of Applied Linguistics, 25, 98–117.

[4] Oxford, R. L. (1992). Research on second language learning strategies. Annual review of applied linguistics, 13, 174-187.

[5] Oxford, R. L. (1992). Research on second language learning strategies. Annual review of applied linguistics, 13, 174-187.

[6] Phakiti, A. (2003). A closer look at the relationship of cognitive and metacognitive strategy use to EFL reading achievement test performance. Language testing, 20(1), 26-56.

[7] Sheorey, R., & Mokhtari, K. (2001). Differences in the metacognitive awareness of reading strategies among native and non-native readers. System, 29(4), 431–449.

[8] Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. Cognitive Science, 12(2), 257–285.

[9] Wang, Z., Guo, Y., Wang, Y., Tu, Y. F., & Liu, C. (2021). Technological solutions for sustainable development: Effects of a visual prompt scaffolding-based virtual reality approach on EFL learners' reading comprehension, learning attitude, motivation, and anxiety. Sustainability, 13(24), 13977.

[10] Wu, J., Wang, Y., Chen, F., Yin, X., & He, Y. (2025). Impact of AI-Powered Adaptive Learning Platforms on English Reading Proficiency: Evidence from Structural Equation Modeling. IEEE Access.