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# The Effect of AI-Supported Scaffolded Academic Reading on Students' Sustainability Reasoning in EFL Contexts


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**Abstract**

This study investigates the effect of AI-supported scaffolded academic reading on students' sustainability reasoning in an EFL context. Using a quasi-experimental design over eight weeks, the research involved twelfth-grade EFL students at a senior high school in Indonesia. The experimental group received AI-assisted scaffolded reading instruction, while the control group participated in conventional reading activities. Data were collected through the Sustainability Reasoning Test (SRT), reflective writing tasks, questionnaires, and classroom observations, then analyzed using t-tests and thematic analysis. The findings show that the experimental group experienced significant improvement in sustainability reasoning, whereas the control group showed minimal progress. Students receiving AI-supported scaffolding demonstrated stronger abilities to identify main claims, evaluate evidence, and construct logical arguments. They also reported greater engagement and confidence in analyzing sustainability-related texts. The study highlights the potential of integrating artificial intelligence with pedagogical scaffolding to enhance academic literacy, deeper comprehension, and sustainability-oriented learning among EFL learners.

[Penelitian ini mengkaji pengaruh pembelajaran membaca akademik dengan scaffolding berbantuan AI terhadap penalaran keberlanjutan siswa dalam konteks EFL. Penelitian menggunakan desain kuasi eksperimen selama delapan minggu pada siswa kelas XII di Indonesia. Kelompok eksperimen memperoleh pembelajaran membaca berbantuan AI, sedangkan kelompok kontrol menggunakan metode konvensional. Data dikumpulkan melalui Sustainability Reasoning Test (SRT), tugas reflektif, kuesioner, dan observasi kelas, kemudian dianalisis menggunakan uji t dan analisis tematik. Hasil penelitian menunjukkan bahwa kelompok eksperimen mengalami peningkatan signifikan dalam penalaran keberlanjutan dibandingkan kelompok kontrol. Siswa pada kelompok eksperimen lebih mampu mengidentifikasi gagasan utama, mengevaluasi bukti, dan menyusun argumen logis. Mereka juga menunjukkan keterlibatan dan kepercayaan diri yang lebih tinggi dalam menganalisis teks keberlanjutan. Penelitian ini menegaskan bahwa integrasi AI dan scaffolding pedagogis berpotensi meningkatkan literasi akademik, pemahaman mendalam, dan pembelajaran berorientasi keberlanjutan bagi pembelajar EFL.]




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## 1. Introduction

The accelerating pace of global environmental, social, and economic challenges has positioned Education for Sustainable Development (ESD) as a critical priority for higher education institutions worldwide. International frameworks, including the United Nations Sustainable Development Goals (SDGs) and the UNESCO Roadmap for ESD, call upon us to equip learners with the competencies necessary to address complex sustainability issues through informed decision-making, critical evaluation of evidence, and reasoned argumentation [1]. Within this context, English as a Foreign Language (EFL) instruction occupies a strategic position: English serves as the dominant medium for disseminating sustainability scholarship, policy documents, and scientific discourse, yet EFL learners frequently encounter significant barriers when engaging with such texts [2].

Research consistently documents that EFL students struggle with the linguistic, structural, and cognitive demands of academic reading in sustainability domains. These difficulties manifest at multiple levels: limited vocabulary knowledge restricts access to domain-specific terminology; syntactic complexity impedes sentence-level comprehension; and unfamiliarity with disciplinary argumentation patterns hinders the extraction of global meaning and logical structure [3]. When sustainability texts incorporate scientific data, multimodal evidence, and interdisciplinary reasoning, these challenges intensify, often confining learners to surface-level decoding rather than enabling the evaluative and synthetic thinking that sustainability literacy demands [4]. Consequently, a critical gap persists between the imperative to integrate ESD into language curricula and the capacity of EFL learners to engage meaningfully with sustainability-themed academic discourse.

Addressing this gap requires structured pedagogical mediation that bridges linguistic comprehension and higher-order reasoning. Scaffolded instruction—characterized by gradual release of responsibility, explicit strategy teaching, metacognitive prompting, and adaptive feedback—has demonstrated effectiveness in supporting EFL learners' progression from surface comprehension to critical analysis [3]. However, traditional scaffolding approaches face practical constraints in diverse, large-enrollment EFL classrooms, where individualized support and timely feedback are difficult to sustain. This limitation has prompted growing interest in technology-enhanced solutions that can deliver personalized, adaptive scaffolds at scale.

This study employed AI-powered educational tools, particularly generative artificial intelligence (AI) platforms such as OpenAI's ChatGPT, to support scaffolded academic reading activities. The AI was used to provide guided questioning, vocabulary support, text summarization, feedback, and critical discussion prompts aimed at enhancing students' sustainability reasoning. AI-driven platforms and generative language models offer capabilities that align closely with established scaffolding principles: they can provide on-demand vocabulary support, generate comprehension prompts tailored to individual learner needs, offer immediate feedback on reading tasks, and adapt difficulty levels based on performance [2]. Recent empirical studies report measurable gains in reading comprehension, engagement, and critical thinking when AI tools are integrated into structured reading instruction [5]. Moreover, AI systems can reduce cognitive load by automating routine support functions, thereby freeing instructional time for higher-order activities such as evidence evaluation, source synthesis, and counterargument generation—competencies central to sustainability reasoning [6].

Despite these promising developments, the integration of AI-supported scaffolding for sustainability-focused academic reading in EFL contexts remains underexplored. Existing research has largely examined AI tools in general EFL reading instruction or sustainability education in isolation, with limited attention to their synergistic potential. Furthermore, questions persist regarding how AI-mediated scaffolds can be designed to foster not merely comprehension but the critical, evaluative, and synthetic reasoning capacities that sustainability literacy requires. This paper addresses these gaps by proposing a conceptual framework that integrates AI-supported scaffolding with ESD principles to enhance EFL learners' engagement with sustainability-themed academic texts. By synthesizing insights from sustainability education, second language reading research, scaffolding theory, and AI in education, this study aims to illuminate pathways for developing pedagogical interventions that enable EFL learners to progress from linguistic comprehension to reasoned engagement with sustainability discourse.

Recent scholarship documents varied approaches to embedding ESD within education curricula. Studies examining sustainability competencies in engineering, education, and interdisciplinary programs reveal that effective ESD integration requires explicit curricular alignment, pedagogical innovation, and assessment frameworks that capture both cognitive and affective dimensions of learning [7]–[9]. Research from diverse national contexts—including Malaysia, Spain,

Switzerland, and Croatia—indicates that while institutional commitment to ESD has grown, significant implementation gaps persist, particularly regarding competencies, pedagogical resources, and disciplinary integration strategies [10].

Academic reading in a foreign language presents multifaceted challenges that operate at lexical, syntactic, discourse, and metacognitive levels. EFL learners commonly experience difficulties with reading speed, vocabulary recognition in context, syntactic parsing of complex sentences, and extraction of main ideas and argumentative structure [6]. These challenges are particularly pronounced when learners encounter discipline-specific texts that employ specialized terminology, dense information packaging, and unfamiliar rhetorical conventions [4].

The medium and mode of reading influence comprehension processes and outcomes. Studies comparing digital and print reading reveal that digital environments often promote rapid scanning and shallow processing, whereas print media support more sustained attention and deeper engagement. For EFL learners navigating complex sustainability texts, these medium effects may interact with linguistic challenges to further constrain comprehension depth. Research on metacognitive strategy use indicates that effective readers employ planning, monitoring, and evaluation strategies to regulate their comprehension, yet many EFL learners lack explicit training in these strategies, particularly when reading scientific and sustainability-related content [11].

Scaffolding, rooted in Vygotskian sociocultural theory, refers to temporary, adjustable support that enables learners to accomplish tasks beyond their independent capability, with the goal of fostering autonomous competence through gradual release of responsibility. In reading instruction, Scaffolding encompasses a range of practices including modeling, guided practice, strategic prompting, feedback, and task structuring [3].

Empirical research on scaffolded reading instruction in EFL contexts demonstrates several key principles. First, explicit strategy instruction—directly teaching learners how to employ specific comprehension and critical reading strategies—yields measurable improvements in reading performance and transfer to new texts. Strategies such as previewing, questioning, summarizing, visualizing, and evaluating have been shown to support both comprehension and critical engagement when taught systematically and practiced with feedback [12].

Second, metacognitive prompting—cues that direct learners' attention to their own thinking processes—enhances self-regulation and comprehension monitoring. Studies report that learners who receive metacognitive prompts demonstrate greater awareness of comprehension breakdowns, more strategic use of fix-up strategies, and improved performance on inferential and evaluative reading tasks [4]. For sustainability-themed texts, metacognitive scaffolds may be particularly valuable in supporting learners' navigation of complex, multimodal, and interdisciplinary content.

Third, gradual release of responsibility—a progression from heavily supported to increasingly independent practice—facilitates skill transfer and autonomous application. Research indicates that learners progress from surface clarification to evaluative questioning when instruction provides staged cognitive prompts that systematically reduce support as competence develops [3]. This principle aligns with the goal of fostering sustainability literacy, which requires learners to move beyond guided comprehension to independent critical analysis of sustainability discourse.

Fourth, adaptive feedback—timely, specific, and personalized responses to learner performance—supports incremental skill building and reduces cognitive load. Studies show that feedback addressing both comprehension accuracy and strategy use enhances learning outcomes, particularly when delivered proximal to task performance [1]. However, providing individualized, timely feedback at scale remains a persistent challenge in traditional classroom settings, motivating interest in technology-enhanced scaffolding solutions.

The integration of AI technologies into language education has accelerated rapidly, driven by advances in natural language processing, machine learning, and generative models. AI applications in EFL contexts span intelligent tutoring systems, adaptive learning platforms, automated writing evaluation, conversational agents, and reading support tools [13].

Recent empirical studies provide evidence of AI's potential to enhance EFL reading comprehension and engagement. A quasi-experimental study involving 80 university-level EFL learners in the United Arab Emirates found that students using AI-driven tools for grammar, vocabulary, and reading comprehension significantly outperformed a control group receiving traditional instruction, with higher post-test scores, increased engagement, and greater satisfaction. Similarly, research on AI-powered reading platforms such as ReadTheory and Actively Learn reports measurable gains in reading fluency, comprehension accuracy, and learner enjoyment, with adaptive algorithms personalizing practice based on individual performance trajectories [5].

Generative AI models, particularly large language models such as ChatGPT, have been explored as tools for scaffolding critical reading tasks. A study examining AI-supported critical reading in EFL classrooms found that when generative AI was integrated into structured tasks requiring bias recognition, evidence evaluation, and counterargument generation, learners demonstrated improved analytic performance and progression from passive answer-seeking to active inquiry. Teachers' perspectives on AI-generated reading comprehension quizzes indicate that such tools can reduce preparation time while maintaining pedagogical quality, though concerns about alignment with learning objectives and assessment validity persist [14].

AI's capacity to deliver adaptive scaffolds aligns closely with established principles of effective reading instruction. AI systems can provide on-demand vocabulary support, generate comprehension questions calibrated to learner proficiency, offer hints and explanations tailored to individual errors, and adjust task difficulty dynamically [5]. These capabilities address key limitations of traditional Scaffolding by enabling personalized support at scale, immediate feedback, and sustained engagement through gamification and progress tracking.

However, research also identifies important constraints and concerns. Studies highlight the need for teacher training in AI tool integration, pedagogical design that embeds AI within structured learning sequences rather than treating it as a standalone solution, and attention to issues of academic integrity, overdependence, and equitable access [13]. Cultural and contextual factors moderate AI effectiveness, with evidence suggesting that learner attitudes, institutional support, and alignment with curricular goals influence implementation success [15].

The convergence of AI-supported scaffolding and sustainability education represents a promising yet underexplored frontier in EFL pedagogy. Recent literature positions AI as a modality for operationalizing scaffolded instruction principles in ways that enable learners to engage with the disciplinary demands of sustainability texts [16]. When AI-mediated tasks are embedded within explicit scaffolding sequences—combining adaptive vocabulary support, metacognitive prompts, guided comprehension questions, and evaluative tasks—they appear to facilitate development of the higher-order competencies central to sustainability literacy.

This conceptual alignment operates at multiple levels. At the cognitive level, AI scaffolds can reduce extraneous cognitive load associated with linguistic decoding, freeing working memory resources for higher-order processes such as inference, evaluation, and synthesis. At the metacognitive level, AI-generated prompts can support planning, monitoring, and evaluation strategies that enhance self-regulated learning and comprehension depth. At the pedagogical level, AI enables differentiation and personalization that address the heterogeneous proficiency levels characteristic of EFL classrooms, while maintaining focus on shared learning goals aligned with sustainability competencies [17].

Empirical evidence supporting this integration remains nascent but suggestive. Studies documenting gains in critical reading performance when AI tools are embedded in structured tasks, combined with research showing that sustainability-themed content can be effectively integrated into language instruction [16], suggest that AI-supported Scaffolding may offer a viable pathway for developing sustainability literacy in EFL contexts. However, a systematic investigation of how specific AI affordances interact with scaffolding principles to support progression from comprehension to critical reasoning about sustainability issues is needed.

Furthermore, the alignment of AI-supported reading instruction with ESD principles extends beyond cognitive outcomes to encompass broader educational goals. ESD emphasizes learner agency, collaborative inquiry, and transformative learning—values that require careful consideration in AI integration [18]. Ensuring that AI tools enhance rather than constrain learner autonomy, support collaborative meaning-making rather than isolated skill practice, and foster critical engagement rather than passive consumption of AI-generated content represents an ongoing pedagogical challenge. Addressing this challenge requires design frameworks that position AI as a mediating tool within sociocultural learning environments, rather than as a replacement for human interaction and pedagogical judgment.

Several previous studies have reported that AI-supported learning environments can positively contribute to students' higher-order thinking skills, including critical thinking, analytical reasoning, and reflective engagement. AI-assisted instructional tools provide immediate feedback, adaptive scaffolding, and guided inquiry that help learners analyze information more critically and evaluate multiple perspectives. These cognitive processes are closely related to sustainability reasoning, which requires students to assess evidence, interpret complex sustainability issues, and construct logical arguments for decision-making. Therefore, it can be assumed that integrating AI-

supported scaffolded reading activities may support the development of students' sustainability reasoning in EFL learning contexts.

## 2. Method

This study employed a quasi-experimental pre-test–post-test control group design to examine the effectiveness of structured AI-supported scaffolded academic reading on sustainability reasoning development in EFL contexts. A quasi-experimental design was selected because intact classroom groups were used without random assignment, a common practice in educational research settings where administrative constraints limit randomization [19]. The study design consisted of two groups. The experimental group received a pre-test, followed by structured scaffolded academic reading integrated with AI support, and concluded with a post-test. The control group completed a pre-test, participated in conventional academic reading instruction without AI support, and subsequently took a post-test. This design enabled comparison of mean differences both within groups and between groups to determine the treatment effect [20].

The study was conducted at a private senior high school in Indonesia within the English subject area. The intervention was implemented during the second semester under the Academic Reading topic. The study lasted for six weeks, with one session per week, and each session lasted approximately 100 minutes. The sustainability texts used during the intervention were drawn from expert-reviewed academic sources focusing on environmental policy, climate change, and sustainable development to ensure authenticity and academic rigor.

The participants consisted of 36 EFL students enrolled in two intact classes. One class (n = 17) was assigned as the experimental group, while the other class (n = 19) served as the control group. All participants demonstrated intermediate English proficiency based on institutional placement assessments. The use of intact classes ensured ecological validity while maintaining comparability between groups through pre-test equivalence checks.

The researcher assumed multiple roles throughout the study, functioning as instructional designer, classroom instructor, observer, and data analyst. In classroom-based educational research, the researcher's presence as instructor allows close monitoring of instructional fidelity and treatment implementation [21]. To minimize potential bias, reflective field notes were documented after each session, and writing assessments were evaluated using inter-rater procedures to ensure scoring reliability.

The instructional procedure followed a structured and chronological progression. During Week 1, both groups completed the Sustainability Reasoning Test (SRT) and a baseline reading comprehension test. No AI assistance was permitted during testing to preserve measurement validity. From Week 2 to Week 6, the experimental group received structured scaffolded instruction integrated with AI support. In each session, students were first introduced to an academic sustainability text. Prior knowledge was activated through guided questions, after which students read the text independently. The AI system then generated structured analytical prompts directing students to identify the main claim, supporting evidence, and logical connectors. When students encountered lexical or structural difficulties, AI-based clarification was permitted. Students subsequently produced short reflective responses, and the AI provided coherence-focused feedback. The instructor facilitated a discussion to consolidate the reasoning structure. Over time, AI scaffolding was gradually reduced following a scaffold reduction logic: full AI prompt support during Weeks 2 and 3, AI assistance only after independent attempts in Week 4, minimal prompts in Week 5, and optional AI coherence reflection in Week 6. This gradual release aligns with the gradual release of responsibility model [22].

In contrast, the control group received conventional scaffolded academic reading instruction consisting of teacher-led explanation, guided comprehension activities, vocabulary support, collaborative discussion, and instructor-provided feedback. Both groups were taught using similar reading materials, instructional duration, and learning objectives to maintain balanced learning conditions. However, unlike the experimental group, the control group did not utilize AI-assisted scaffolding tools for argument mapping, reflective questioning, or analytical reading support.

Several instruments were employed in this study. The Sustainability Reasoning Test (SRT) measured claim identification, evidence evaluation, logical connector analysis, and argument construction. The instrument demonstrated acceptable internal consistency (Cronbach's Alpha = .87) [23]. In addition, students completed a 250-word reflective writing task on sustainability issues, assessed using a four-dimensional rubric (claim clarity, evidence integration, logical coherence, and sustainability awareness), scored on a 1–4 scale. Inter-rater reliability analysis yielded Cohen's κ =

.78, indicating substantial agreement [24]. A 10-item multiple-choice reading comprehension test was administered to assess literal and inferential understanding. An observation checklist was also used to monitor engagement, reasoning behaviors, and scaffold internalization during instruction. Furthermore, a student perception questionnaire was distributed to capture students' experiences with structured AI-supported learning.

Data were collected through multiple sources, including pre-test and post-test scores, reflective writing samples, classroom observation notes, and questionnaire responses. All participants provided informed consent prior to participation, and all data were anonymized to protect confidentiality.

Quantitative data were analyzed using SPSS. Prior to hypothesis testing, normality was examined using the Kolmogorov–Smirnov test, and homogeneity of variance was assessed using Levene's Test. Paired-sample t-tests were conducted to determine within-group improvement, and independent-sample t-tests were used to compare post-test differences between groups. Effect sizes were calculated using Cohen's d and interpreted according to established benchmarks.

Qualitative data from reflective writing were analyzed using thematic analysis procedures [25]. The process involved familiarization with the data, initial coding, theme identification, theme refinement, and interpretative synthesis. The analysis focused on four thematic dimensions: claim clarity, evidence integration, logical coherence, and sustainability awareness.

To ensure methodological rigor, several validity and trustworthiness strategies were employed. Internal validity was strengthened through pre-test equivalence checks, controlled instructional duration, and comparable text difficulty across groups. Reliability was ensured through internal consistency testing and inter-rater scoring procedures. Qualitative credibility was supported through triangulation of multiple data sources (test scores, writing samples, and observation), peer debriefing with an expert, and maintenance of an audit trail documenting instructional materials and analytical decisions. These procedures align with established criteria for qualitative trustworthiness [26].

Ethically, the study adhered to institutional research guidelines. Participation was voluntary, and students were informed that they could withdraw at any time without academic consequences.

## 3. Results

Descriptive statistics were calculated to examine students' sustainability reasoning performance before and after the instructional intervention. The experimental group received structured AI-supported scaffolded academic reading instruction, while the control group received conventional reading instruction without AI assistance.

Table 1. Descriptive Statistics of Sustainability Reasoning Test Scores

| Group | N | Pre-test Mean | SD | Post-test Mean | SD |
|---|---|---|---|---|---|
| Experimental | 17 | 84.53 | 11.07 | 95.18 | 12.30 |
| Control | 19 | 81.63 | 15.17 | 83.21 | 15.25 |

The descriptive results indicate that students in both groups demonstrated comparable levels of performance prior to the intervention. Such baseline comparability is important in quasi-experimental studies to ensure that observed differences are likely associated with the instructional treatment rather than initial group disparities [20].

Prior to conducting parametric statistical tests, the assumptions of normality and homogeneity of variance were examined.

Table 2. Normality and Homogeneity Tests

| Test | Statistic | df | Sig. |
|---|---|---|---|
| Kolmogorov–Smirnov (Pre-test) | 0.146 | 36 | .051 |
| Kolmogorov–Smirnov (Post-test) | 0.132 | 36 | .078 |
| Levene's Test | 0.87 | 1,34 | .357 |

The Kolmogorov–Smirnov test indicated that the data were normally distributed ($p > .05$). The homogeneity of variance assumption was also satisfied according to Levene's test. Therefore, parametric statistical analyses were considered appropriate for examining group differences [19].

Paired-sample t-tests were conducted to determine whether students' sustainability reasoning performance improved after the instructional intervention.

Table 3. Paired-Sample t-test Results

| Group | Mean Difference | t | df | Sig. | Cohen's d | Effect Size |
|---|---|---|---|---|---|---|
| Experimental | -10.65 | -2.70 | 16 | .016 | 0.66 | Moderate |
| Control | -1.58 | -0.47 | 18 | .641 | 0.11 | Small |

The descriptive results indicate that both groups showed relatively comparable performance at the baseline. However, after the intervention, the experimental group demonstrated a noticeable increase in post-test scores ($p < .05$), while the control group showed only slight improvement.

An independent-sample t-test was conducted to compare post-test performance between the two groups.

Table 4. Independent-Sample t-test Results

| Group | Mean | SD | N |
|---|---|---|---|
| Experimental | 84.53 | 12.30 | 17 |
| Control | 81.63 | 15.25 | 19 |

| Test | t | df | Sig. | Cohen's d |
|---|---|---|---|---|
| Independent t-test | 0.63 | 33.67 | .533 | 0.21 |

Although the experimental group achieved a slightly higher post-test mean score, the difference between groups was not statistically significant. However, the moderate within-group improvement observed in the experimental group suggests that the scaffolded AI-supported learning environment contributed to students' reasoning development.

The increase in the experimental group's mean score from pre-test to post-test suggests that AI-supported scaffolded instruction contributed positively to students' sustainability reasoning development. In contrast, the control group's marginal improvement indicates that conventional instruction alone may not sufficiently support higher-order reasoning skills.

Qualitative analysis of students' reflective writing responses revealed progressive development in sustainability reasoning. Thematic analysis identified four key dimensions: claim clarity, evidence integration, logical coherence, and sustainability awareness. Students in the experimental group increasingly demonstrated the ability to identify central arguments within sustainability texts and connect supporting evidence to broader environmental and social implications.

For example, one student wrote:

> *"The main claim of the text is that sustainable development requires cooperation between governments, industries, and citizens."*

Another student demonstrated evidence integration:

*"Countries that invest in renewable energy can reduce emissions while maintaining economic growth."*

These examples illustrate the development of structured reasoning patterns aligned with the instructional objectives.

Classroom observations conducted throughout the six-week intervention revealed notable changes in students' reading behavior and reasoning processes. During the initial sessions, many students relied heavily on AI prompts to interpret sustainability texts and identify key arguments. However, as the intervention progressed and scaffolding was gradually reduced, students demonstrated increased independence in analyzing texts. By Week 6, students were able to independently identify claims, evaluate supporting evidence, and construct coherent arguments

about sustainability issues. Classroom discussions also became more analytical, with students questioning the credibility of sources and comparing alternative viewpoints.

These observations suggest that the scaffolded AI system supported the internalization of analytical reading strategies rather than creating dependency on technological assistance.

Student perceptions of the learning process were analyzed using descriptive statistics and thematic interpretation of open-ended responses.

Table 5
Student Perception Questionnaire

| Dimension | Mean Response |
|---|---|
| Learning Support | 3.86 |
| Reasoning Development | 3.74 |
| Overall Perception | 3.79 |

The results indicate generally positive perceptions of the learning process. Students reported improvements in their ability to identify main claims, evaluate evidence, and recognize logical connectors in academic texts.

Students' open-ended responses highlighted several perceived benefits of the instructional activities.

Common themes included: Structured learning support

*"The clear explanation and step-by-step examples helped me understand the material better."*

Argument structure awareness:

*"Identify main claim and supporting evidence was the most helpful part."*

Exposure to new knowledge:

*"We learn about something new."*

Students also reported several challenges, particularly during the early stages of the intervention: Difficult vocabulary.

*"At first it was difficult to understand some vocabulary."*

Text complexity:

*"The challenge was the text was too long."*

Argument analysis difficulty

*"Sometimes it was challenging to distinguish strong and weak evidence."*

These responses suggest that although students initially experienced difficulty engaging with complex academic texts, structured reading activities gradually supported the development of reasoning skills.

## 4. Discussion

The present study examined the effectiveness of AI-supported scaffolded academic reading in enhancing sustainability reasoning among EFL learners. The findings provide several insights into the role of AI technologies in supporting academic literacy and sustainability education.

First, the quantitative results demonstrate that students in the experimental group experienced significant improvement in their reasoning performance after participating in scaffolded reading activities. This finding aligns with previous research indicating that AI tools can support EFL learners by assisting them in navigating complex reading tasks and overcoming comprehension difficulties [2], [12]. AI-generated prompts and guided questions may help learners identify key textual elements, such as claims and supporting evidence, which are essential components of critical academic reading.

From a pedagogical perspective, the results support the concept of distributed scaffolding, in which instructional support is provided through multiple sources, including digital tools and guided instructional activities [22]. In the present study, AI tools functioned as supplementary scaffolding mechanisms that guided students' reading processes and encouraged deeper engagement with sustainability texts.

Second, the findings highlight the importance of metacognitive strategy development in academic reading. Students gradually demonstrated greater ability to analyze arguments and evaluate evidence within sustainability-related texts. Previous research has emphasized that

effective readers employ metacognitive strategies such as planning, monitoring, and evaluating their comprehension during reading tasks [4]. AI-assisted prompts may support these strategies by encouraging learners to reflect on the structure and logic of the texts they read.

Third, the integration of sustainability-related reading materials appears to contribute to students' broader understanding of environmental and social issues. Sustainability education aims to develop competencies such as critical thinking, systems thinking, and responsible decision-making [7], [18]. Embedding sustainability topics within language learning activities, therefore, provides opportunities for students to simultaneously develop linguistic competence and sustainability awareness [16].

The findings also correspond with studies indicating that AI technologies can enhance engagement and motivation in language learning environments. Digital tools can create interactive learning experiences that encourage students to actively participate in reading activities and explore complex topics more independently [13], [16].

Furthermore, the qualitative findings from student reflections and classroom observations suggest that scaffolded instructional approaches may help learners internalize analytical reading strategies over time. As scaffolding support was gradually reduced, students began to demonstrate greater independence in identifying arguments and evaluating evidence. This progression reflects the fundamental goal of Scaffolding, which is to gradually transfer responsibility for learning from the instructor to the learner [22].

Finally, the integration of AI tools in sustainability-focused reading activities reflects broader trends in digital transformation within language education. Emerging technologies are increasingly being used to support innovative instructional approaches and promote more adaptive learning environments in EFL contexts [1], [3].

Overall, the findings suggest that AI-supported scaffolded academic reading can facilitate the development of sustainability reasoning by combining cognitive support, metacognitive strategy development, and exposure to sustainability-related discourse. Such instructional approaches may contribute to preparing students to critically engage with complex global challenges presented in academic texts.

The conceptual relationship can be summarized as follows:

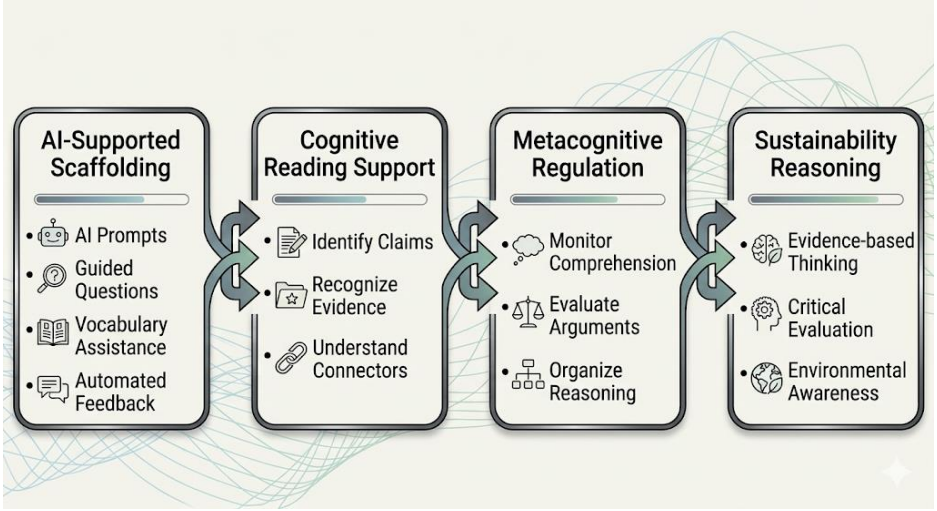


Figure 1. Conceptual Model for AI-Supported Scaffolding to Foster Sustainability Reasoning in EFL Higher Education.

Based on the empirical findings of this study, a conceptual model of AI-supported scaffolding for sustainability reasoning is proposed (see Figure 1). This model illustrates the transition from automated linguistic support to higher-order metacognitive regulation. Specifically, it demonstrates how initial AI-supported scaffolding—provided through adaptive prompts and vocabulary clarification—serves as a necessary cognitive anchor that reduces the extraneous load of processing complex academic texts. By alleviating these lower-level linguistic barriers, the model suggests that students can reallocate their cognitive resources toward metacognitive regulation, such as evaluating the validity of environmental arguments and synthesizing diverse perspectives.

The progression culminates in the development of Sustainability Reasoning, where the learner no longer relies on external AI support but internalizes the analytical strategies required to navigate global sustainability challenges. This transition aligns with the 'fading' principle of scaffolding, where AI-driven interventions are gradually superseded by the student's autonomous critical thinking. Ultimately, this framework provides a pedagogical roadmap for EFL educators to move beyond traditional comprehension exercises toward a more transformative, inquiry-based approach to environmental education.

This sequential process model details the theoretical pathway from technological support to critical environmental literacy. Initial AI-Supported scaffolding uses targeted prompts, guided questions, and vocabulary assistance to build Academic Readiness. This support directly facilitates Cognitive Reading Support, enabling students to identify claims and recognize evidence within complex texts. Advanced Metacognitive Regulation, including argument evaluation, then acts as a necessary bridge for advancing Critical reasoning skills, leading to the final outcome of Sustainability Reasoning, characterized by critical evaluation and environmental awareness.

This model suggests that AI technologies can play a meaningful role in supporting EFL learners' engagement with complex global issues by strengthening academic literacy and analytical reasoning skills. Future research could explore longer intervention periods, larger sample sizes, and different AI scaffolding designs to further examine the potential of AI-supported academic reading in sustainability education.

This finding reinforces the role of AI as a cognitive and metacognitive support system rather than merely a technological tool. The structured prompts generated by AI appear to function as guided scaffolding, enabling learners to gradually internalize analytical reading strategies. This aligns with sociocultural learning theory, where external support is progressively transformed into internal cognitive competence.

## 5. Conclusion

This study investigated the impact of AI-supported scaffolded academic reading on students' sustainability reasoning in an EFL context. The findings indicate that structured instructional support, combined with AI-assisted prompts and guided analytical activities, can contribute to the development of students' reasoning skills when engaging with sustainability-related texts.

Quantitative results revealed that students who experienced scaffolded learning with AI assistance demonstrated greater improvement in reasoning performance compared to those in the conventional learning group. The scaffolded approach appeared to help students identify main claims, analyze supporting evidence, and evaluate arguments more systematically.

Qualitative findings from reflective writing, classroom observations, and student perception questionnaires further supported these results. Students reported that structured learning activities helped them better understand the organization of arguments and develop more confidence in analyzing sustainability issues. Over time, students became more capable of independently evaluating textual evidence and organizing their reasoning.

One strength of this study lies in the integration of AI-assisted scaffolding within sustainability-oriented academic reading instruction in an EFL context, which remains relatively underexplored in previous research. The combination of quantitative and qualitative data also provided a more comprehensive understanding of students' reasoning development. However, this study was limited by its relatively small sample size and short intervention period, which may affect the generalizability of the findings. In addition, the study focused on a single educational context, and different results may emerge in other learning environments or proficiency levels. Therefore, future research is recommended to involve larger and more diverse participant groups, longer intervention durations, and comparative investigations of different AI-supported instructional models to further explore the role of AI in sustainability education and academic literacy development.

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**Informed Consent**

Informed consent was obtained from all participants involved in this study prior to the data collection process. Participants were informed about the purpose of the study, the voluntary nature of participation, and the confidentiality of their responses.

**Ethical Approval**

This study followed ethical guidelines for educational research involving human participants. The study procedures were conducted in accordance with institutional research ethics standards. All collected data were anonymized to ensure participant confidentiality.

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