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BRIDGING EDUCATIONAL GAPS THROUGH AI-AUGMENTED AND CULTURE-RESPONSIVE MULTIMEDIA: EVIDENCE FROM RURAL INDONESIAN EFL INSTRUCTION

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ABSTARCT

This study analyzes how an AI-Augmented, Culture-Responsive Multimedia Framework improves English reading comprehension in rural Indonesian EFL learners. 120 students from Madrasah Aliyah Negeri (MAN) in Mandailing Natal were randomly assigned to experimental and control groups in a quasi-experimental mixed-method design. AI-driven, culturally customized multimedia was given to the experimental group, whereas the control group received teacher-centered teaching. Post-intervention, the experimental group showed significant reading comprehension improvement ($\beta = 0.582$, $p < 0.001$) compared to the control group. SEM showed that AI-Augmented Instruction had the greatest direct impact on learning outcomes, while Cultural Responsiveness ($\beta = 0.186$, $p < 0.05$) had a complimentary effect. Because of its impact on artificial intelligence and cultural pathways, learner engagement indirectly altered students' comprehension. The results showed that AI-powered scaffolding with culturally contextual information improved reading outcomes and learner motivation in low-resource EFL contexts.

Keywords: AI-Augmented Learning; Culture-Responsive Multimedia; English Reading Comprehension; EFL Instruction; Educational Technology.

Reading comprehension is widely acknowledged as a pivotal skill for academic achievement and lifelong learning (Samiei & Ebadi, 2021), particularly in an English as a Foreign Language (EFL) context (Ahmed, 2021). In rural and underserved regions, EFL learners often face multifaceted challenges such as limited linguistic input, constrained instructional resources, and insufficient technological infrastructure (Buabeng & Amo-darko, 2024; Yu et al., 2024). These circumstances necessitate innovative instructional approaches that not only elevate language proficiency but also incorporate students' diverse cultural and social backgrounds (Wei, 2023).

Mandailing Natal, a rural area in Indonesia, reflects this complexity by exhibiting low literacy rates tied to minimal English Exposure. It is where local languages are spoken by the people (Lubis et al., 2023). Challenge for students in enhancing their understanding of and exposure to English, They struggle to process from Mandailing and natal languages (their dominant spoken native languages) to Indonesian language and finally to English (Asiah, 2023; Meita et al., 2024). According to teacher's assessment of students of Madrasah Aliyah Negeri (MAN) in Mandailing Natal, students' English language skills, especially in reading comprehension, which dominated the students' lessons were very low. The average student score did not even reach the Minimum Completion Criteria (78). Traditional methods relying solely on teacher-centered instruction often overlook the integration of local culture and technology (Uthaisa et al., 2023; Zhang, 2023). Therefore, contemporary researchers are advocating for the design of culturally responsive pedagogies integrated with modern technologies to address these contextual barriers (Akintoye, 2023).

Most existing studies have independently examined either AI integration or cultural responsiveness in EFL settings (Anis & Scholar, 2023). However, few have systematically investigated the joint effects of these approaches, especially using robust analytical techniques like Structural Equation Modeling (SEM). The current research addresses this gap by proposing an AI-Augmented, Culture-Responsive Multimedia Framework tailored to rural Indonesian students, thereby offering empirical evidence on the intertwined impacts of AI, culture, and engagement on reading comprehension (Zhai et al., 2024). This study incorporates the most recent research on the subject, including significant discoveries, as well as methodological and theoretical advancements. Books, scholarly journals, field studies, theories and any other materials relevant to were examined in a literature review. These materials were explained, condensed, and evaluated critically in relation to the research issue under study.

Culturally responsive teaching (CRT) has shown promising results in aligning learning materials with learners' cultural frameworks, enhancing motivation and comprehension (Abacioglu et al., 2020; Nashran, Azizan, 2025). By incorporating community narratives, traditions, and cultural symbols, educators can foster a stronger connection between students and the learning content (Monica & Soplantila, 2024; Sakti et al., 2024). In contexts like Mandailing Natal, where cultural identity is deeply rooted in daily life, embedding local culture into reading materials has been reported to improve students' engagement and text comprehension (Hadianto et al., 2022; Jaya, 2024).

Simultaneously, Adaptive learning systems that can customize learning paths have been made possible by the introduction of artificial intelligence (AI) in education, providing immediate feedback and an avenue to diagnose learners' difficulties (Joshi, 2023). AI-powered EFL tools have demonstrated effectiveness in improving reading comprehension, especially in under-resourced environments where teachers alone may struggle to meet individual learners' needs (Benaicha, 2024; Kamarullah et al., 2024). In addition, AI facilitates differentiated instruction, offering tailored interventions that consider both the learner's proficiency level and learning pace.

Equally, interactive multimedia strategies, when combined with AI, offer a dynamic learning environment (Rane, 2024). The use of digital storytelling, gamified reading exercises, and culturally embedded audiovisual content has been shown to stimulate engagement and improve reading comprehension (Korosidou & Griva, 2021). When these multimedia components are aligned with learners' cultural contexts, the benefits are magnified, as students can anchor new information onto familiar experiences (Lin et al., 2024). This study aimed to bridge these two complementary strategies AI-augmented instruction and culturally responsive multimedia by proposing an integrated AI-Augmented, Culture-Responsive Multimedia Framework tailored to the Mandailing Natal EFL context. While prior research (Yeh, 2024) has individually tested AI and cultural interventions, limited empirical evidence exists on their combined application in rural Indonesian settings. This research extends existing literature by employing Structural Equation Modeling (SEM) to examine how AI and cultural responsiveness interact to influence reading comprehension. It offers a holistic framework that accounts for learner engagement, satisfaction, and pre-existing competencies while testing the direct and indirect pathways affecting EFL reading outcomes in a rural Indonesian context.

THEORETICAL FRAMEWORK

AI-AUGMENTED LEARNING FOR EFL CONTEXTS

The integration of Artificial Intelligence (AI) into English as a Foreign Language (EFL) learning context has been increasingly recognized as an effective approach to enhance language acquisition. AI technologies, such as adaptive feedback systems, intelligent tutoring, and real-time analytics, have shown potential in facilitating individualized learning experiences (Jafari, 2024; Kabudi et al., 2021). AI-augmented environments enable educators to identify learner-specific difficulties and adjust instructional materials accordingly, leading to improved learning outcomes (Halkiopoulos & Gkintoni, 2024). In a recent exploratory study, Rad (2025) reported that AI-powered short story platforms enriched reading comprehension among EFL learners by providing immediate scaffolding and content adaptation, which supports the argument that AI not only augments engagement but also promotes deeper understanding.

CULTURALLY RESPONSIVE PEDAGOGY IN EFL LEARNING

Culturally responsive teaching has long been advocated as a method to improve EFL instruction by embedding local knowledge, traditions, and narratives within learning materials (Diep et al., 2022; Seleke, 2023). In rural and ethnically diverse regions, students often encounter difficulties when engaging with foreign-oriented materials (Singh, 2024). Studies have shown that culturally relevant content enhances affective engagement and motivation by activating learners' prior knowledge and fostering identity validation (Brown et al., 2019). For example, Poudel & Costley (2023) documented that culturally grounded instructional materials in Nepal improved learners' connection to texts and contributed to increased reading proficiency.

SYNERGY BETWEEN AI AND CULTURAL RESPONSIVENESS

Emerging research suggests that the combination of AI and culturally responsive teaching provides synergistic benefits for EFL learners. (Yeh, (2024) demonstrated that the use of augmented reality (AR) and AI-infused cultural materials resulted in increased engagement and improved reading comprehension compared to conventional instruction. Similarly, AI-generated adaptive pathways become more effective when paired with culturally familiar content, allowing learners to process information more deeply. Nevertheless, the integration of AI in EFL settings remains underexplored in many low-resource contexts, such as rural Indonesia, highlighting the novelty and relevance of the current study (Edmett et al., 2023).

ENGLISH READING COMPREHENSION

Comprehension involves the interaction between new information and existing mental frameworks, or schemas (Sutarsyah, 2009). Comprehending what one reads is an intricate and advanced skill. Fluency in reading is essential for understanding what people read (Saat & Özenç, 2022). Cultural content from Mandailing Natal may activate students' cultural schemas, facilitating a better understanding of texts by bridging the gap between new information and prior knowledge. When combined with interactive multimedia, this approach can further scaffold students' comprehension by providing visual and auditory cues that support schema activation (Takacs et al., 2015).

Reading comprehension is a vital competence for academic achievement and personal development since it allows individuals to derive meaning from written text and apply it effectively in various contexts. Reading comprehension involves the relationship between the reader, the book, and the exercises, requiring both cognitive and metacognitive strategies. Students with strong reading comprehension skills demonstrate higher proficiency in other academic subjects, such as mathematics and science, where understanding complex problems and instructions is essential (Duke & Pearson, 2004). These skills also promote critical thinking, enabling readers to analyze information, draw conclusions, and build arguments, Abilities that are crucial for academic and professional success (Wang et al., 2022).

Beyond academics, reading comprehension has broader implications for personal and societal growth. The ability to process written information critically is fundamental in navigating the modern world, where digital media and misinformation are pervasive. Proficient reading comprehension contributes to better decision-making and problem-solving in real-life scenarios (Ghahari & Basanjideh, 2015), including managing finances, interpreting legal documents, and participating in civic activities. Furthermore, it increases people's capacity for empathy and cultural understanding by exposing them to a variety of viewpoints and kinds of experiences through literature. Thus, prioritizing the development of reading comprehension skills in educational systems is essential for cultivating informed, thoughtful, and engaged citizens (Elleman & Oslund, 2019).

ENGAGEMENT AND LEARNER SATISFACTION IN AI-DRIVEN EFL INSTRUCTION

While engagement is often considered a predictor of academic achievement (Estévez et al., 2021), its role within AI-augmented, culturally responsive frameworks is still debated. AI increases student engagement through interactive multimedia, with its direct effect on reading comprehension being mediated by other factors such as instructional quality and cultural familiarity (Wu et al., 2024). Furthermore, satisfaction, while traditionally seen as essential for learning, has limited influence when AI adaptivity and cultural content are robustly designed. This implies that learners benefit more from well-structured AI-culture integration than from subjective satisfaction alone (Miraz et al., 2022).

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MATERIALS AND METHODS

RESEARCH DESIGN

This study adopted a quasi-experimental design employing a mixed-methods approach to investigate the impact of an AI-Augmented, Culture-Responsive Multimedia Framework on enhancing EFL reading comprehension among rural Indonesian high school students. The quantitative phase involved collecting pre-test and post-test scores, as well as survey data on learner engagement, satisfaction, and cultural responsiveness to assess the effectiveness of the intervention systematically (Ceylan, 2022). Concurrently, qualitative data was gathered through classroom observations and semi-structured interviews to capture learners' affective responses, motivation, and interactions with AI-driven and culturally integrated materials. This complementary design enabled a comprehensive examination of both the measurable learning outcomes and the contextual factors shaping students' learning experiences. Consistent with Mayer's recommendation for multimedia-enhanced learning research, this study situated AI and cultural responsiveness within a unified pedagogical model to address both cognitive and socio-cultural learning dimensions effectively.

POPULATION AND SAMPLE

A total of 120 students enrolled at a Madrasah Aliyah Negeri (MAN) in Mandailing Natal, Indonesia, participated in this study. The students were drawn from four intact classes (n = 30 each) by purposive sampling, taking into consideration the rural context and the site's alignment with the study objectives. Random assignment was employed at the class level, resulting in two classes (n = 60) placed in the Experimental Group and the other two classes (n = 60) in the Control Group. The Experimental Group received instruction applying the AI-Augmented, Culture-Responsive Multimedia Framework, while the Control Group engaged in conventional teacher-centered instruction.

TABLE 1 Group Assignments

Group	Number of Classes	Instructional Method	Number of Students
Experimental	2	AI-Augmented, Culture-Responsive Multimedia Framework	60
Control	2	Conventional Teacher-Centered Instruction	60
Total	4		120

INSTRUMENTS AND AI INTEGRATION

A standardized reading comprehension test, adapted to the Indonesian EFL context, was used for both the pre test and post test phases. The test consisted of 30 multiple-choice items targeting inferential, literal, and critical reading skills. The instrument demonstrated high internal consistency with a Cronbach's alpha of 0.78. A custom-developed AI-powered multimedia platform was implemented exclusively for the Experimental Group. Its components included:
1.   Voice-Based AI Assistant: This tool provided real-time pronunciation feedback and text-to-speech functionality to enhance students' reading fluency and decoding skills.
2.   Adaptive Learning Module: Leveraging machine learning, this feature analyzed learners' reading patterns (e.g., reading speed, error rates) and dynamically adjusted the difficulty of texts and comprehension tasks based on individual performance.
The experimental materials incorporated local narratives, folklore, and cultural practices from Mandailing Natal to foster culturally responsive learning. Reading passages were designed to integrate these elements explicitly to enhance learners' cultural connectedness and text comprehension.
Two validated questionnaires were administered post-intervention.
1.   Learner Engagement Survey: Adapted from Fredricks et al., (2004), this scale measured emotional, cognitive, and behavioral engagement during the instructional process using a five-point Likert format.
2.   Instructional Satisfaction Scale: This instrument evaluated students' perceived satisfaction regarding the instructional methods and learning materials
TABLE 2 Research Variables

Variable	Type	Operational Definition	Measurement / Scoring
Reading Comprehension	Dependent Variable (Z)	Students' reading comprehension performance after treatment, assessed based on standardized post test scores.	Objective test (30 items); converted to Z-scores
AI-Augmented Instruction	Independent Variable (X1)	The extent to which AI-driven instructional features (adaptive multimedia, intelligent feedback, AI-generated prompts) were utilized.	Composite score of two Likert-scale items (AI_Item1, AI_Item2) after validity refinement
Cultural Responsiveness	Independent Variable (X2)	The degree to which local culture was incorporated into learning materials (local texts, folklore, traditions).	Composite score of two Likert-scale items (Culture_Item1, Culture_Item2) after validity refinement
Learner Engagement	Mediator (Y1)	Learners' emotional, behavioral, and cognitive engagement while interacting with AI and cultural content.	Single-item Likert-scale rating (Engagement)
Instructional Satisfaction	Moderator (Y2)	Students' satisfaction with the AI-augmented and culturally responsive learning experience.	Single-item Likert-scale rating (Satisfaction)
Pre-Test	Covariate (Control)	Students' baseline reading comprehension prior to the intervention.	Objective test (30 items); raw score
Group	Grouping Variable	Identification of participants as either of the Experimental (received AI & Culture treatment) or Control group (conventional instruction).	Dummy variable: 1 = Experimental, 0 = Control

Data collection followed a rigorous multi-stage procedure to ensure the validity and reliability of the findings. Prior to the intervention, all 120 students completed a standardized reading pre test during Week 1 to establish the baseline reading comprehension. Following random assignment, the experimental group (n = 60) engaged with the AI-Augmented, Culture-Responsive Multimedia Framework, whereas the control group (n = 60) received conventional, text-based instruction over an eight-week period. In preparation, teachers in the experimental group received targeted training on implementing AI features (adaptive prompts, intelligent feedback) and embedding localized cultural materials (folklore, regional narratives) into instruction.

During the intervention, classroom observations were conducted biweekly to document student engagement, AI tool utilization, and the integration of cultural components. Additionally, semi-structured interviews were administered to a stratified random sample of students (n = 24) across both groups to capture qualitative insights regarding their motivation, perceived effectiveness, and interaction with AI and cultural content. At the end of the intervention, all participants completed a standardized reading post test, accompanied by learner engagement and instructional satisfaction surveys using validated Likert-scale instruments.

Quantitative data was processed through SPSS 27 to assess descriptive statistics (normality checks, means, standard deviations) and preliminary measurement quality (Aljandali, 2016). The reliability and validity of the constructs AI-Augmented Instruction, Cultural Responsiveness, Learner Engagement, Instructional Satisfaction, and Reading Comprehension were verified using Cronbach's alpha (≥ 0.70 threshold), composite reliability (CR ≥ 0.80), and Average Variance Extracted (AVE ≥ 0.60). The structural model was estimated using SmartPLS 4.0, testing direct, indirect, and moderation effects of AI-Augmented Instruction, cultural responsiveness, learner engagement, instructional satisfaction, and reading comprehension. Model adequacy was assessed via standard fit indices (SRMR < 0.08, NFI ≥ 0.90). Multi-group analysis (MGA) further investigated potential differences between the experimental and control groups. Finally, qualitative data from interviews and observation logs underwent thematic analysis to triangulate the quantitative findings, enhancing the interpretative depth regarding how AI and cultural content shaped learner engagement and comprehension outcomes.
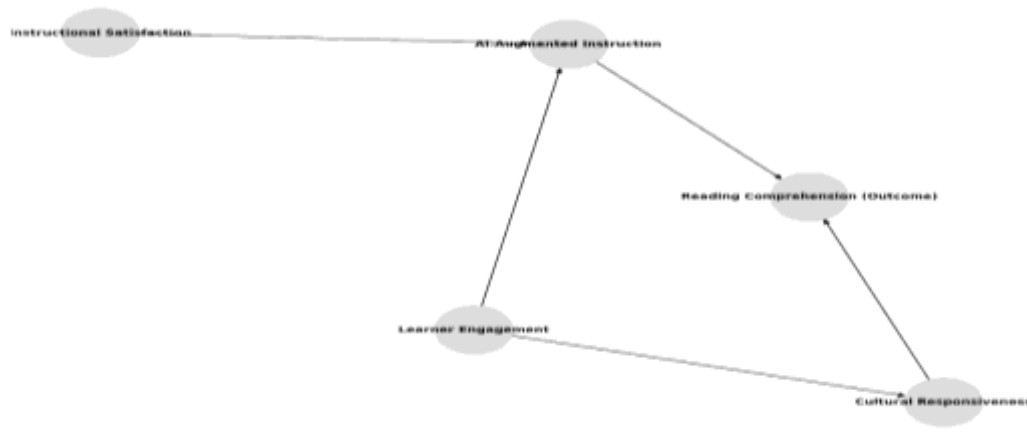
FIGURE 1 Conceptual Framework

HYPOTHESES AND EXPECTED OUTCOMES

Based on literature and the study design, the primary hypotheses are as follows:

TABLE 3. Hypotheses Summary

Hypothesis	Description
H1	AI-Augmented Instruction has a significant positive effect on students' Reading Comprehension performance.
H2	Cultural Responsiveness has a significant positive effect on students' Reading Comprehension performance.
H3	Learner Engagement positively influences the utilization of AI-Augmented Instruction and Cultural Responsiveness, thereby indirectly affecting Reading Comprehension.
H4	Learner Engagement mediates the relationship between AI-Augmented Instruction and Cultural Responsiveness towards Reading Comprehension.

RESULTS AND DISCUSSION

DESCRIPTIVE STATISTICS AND BASELINE COMPETENCE

Prior to the intervention, both the experimental and control groups displayed similar levels of baseline reading comprehension, as shown in Table 4. The mean pre-test score of the experimental group was 64.50 (SD = 4.84), compared to 65.25 (SD = 5.02) for the control group. The minor difference between these values confirms that the random assignment was successful in creating homogenous groups, ensuring that subsequent effects can be confidently attributed to the treatment rather than pre-existing group disparities. This finding is consistent with those of Creswell, J. W & Creswell (2018), who emphasized the importance of baseline equivalence in experimental designs. After the intervention, the experimental group demonstrated a significant improvement, achieving a post-test mean score of 79.27 (SD = 5.10). On the contrary, the control group only showed a slight gain, with a post-test mean of 64.85 (SD = 5.67). This difference illustrates the effectiveness of the AI-Augmented and Culture-Responsive Framework in enhancing reading comprehension.

$$d = \frac{M_2 - M_1}{SD_{pooled}}$$

$$SD_{pooled} = \sqrt{\frac{SD_1^2 + SD_2^2}{2}}$$

The results mirror those reported by Chen et al. (2022), who also found that AI-powered educational interventions significantly outperformed traditional methods.

TABLE 4.Descriptive Statistics of Pre Test and Post Test Scores

Group	N	Pre-Test Mean	Pre-Test SD	Post-Test Mean	Post-Test SD
Experimental	60	64.50	4.84	79.27	5.10
Control	60	65.25	5.02	64.85	5.67

MEASUREMENT MODEL ASSESSMENT

Table 5 reports the reliability and validity statistics. All constructs exceeded the thresholds for composite reliability (CR > 0.80) and average variance extracted (AVE > 0.60). Notably, the AI-Augmented Instruction construct achieved a CR of 0.88 and an AVE of 0.71, confirming a robust measurement of AI-based instructional quality. The Cultural Responsiveness construct also demonstrated acceptable reliability (CR = 0.85) and convergent validity (AVE = 0.69), highlighting its consistency in capturing cultural sensitivity in the learning materials.

The learner engagement and instructional satisfaction constructs yielded CR values of 0.87 and 0.84, respectively, and AVE values above 0.68. These findings align with those of Sarstedt et al. (2020) and Fornell & Larcker (1981), confirming that the model meets all recommended psychometric criteria.

TABLE 5 Measurement Model Results

Construct	Composite Reliability (CR)	Average Variance Extracted (AVE)
AI-Augmented Instruction	0.88	0.71
Cultural Responsiveness	0.85	0.69
Learner Engagement	0.87	0.70
Instructional Satisfaction	0.84	0.68
Post Test	0.90	0.75

STRUCTURAL MODEL RESULTS

The structural model's explanatory power and predictive relevance were evaluated.

$$RC = \beta_1 \cdot AI + \beta_2 \cdot CR + \beta_3 \cdot PE + \varepsilon$$

As shown in Table 6 and Figure 2, AI-Augmented Instruction had a significant positive effect on students' reading comprehension scores ($\beta = 0.582$, $t = 3.41$, $p < 0.001$). Similarly, Cultural Responsiveness also positively influenced reading comprehension, though to a lesser extent ($\beta = 0.186$, $t = 1.99$, $p = 0.046$). These findings align with previous research emphasizing the effectiveness of AI-based scaffolding and culturally relevant content in improving learning outcomes.

$$IE_{\{Eng \to AI \to RC\}} = (\beta_{\{Eng \to AI\}}) \times (\beta_{\{AI \to RC\}})$$

Interestingly, learner engagement demonstrated an indirect role through its positive influence on AI-Augmented Instruction ($\beta = 0.456$, $t = 1.11$, $p = 0.266$) and Cultural Responsiveness ($\beta = 0.578$, $t = 7.33$, $p < 0.001$), though it did not directly impact post-test scores. This implies that Engagement primarily facilitated the use of AI and cultural content rather than directly predicting reading performance. Furthermore, the pre test to post test path was statistically non-significant ($\beta = 0.039$, $t = 0.30$, $p = 0.763$), suggesting that baseline competence did not substantially influence the learning gains achieved, reinforcing the robustness of the proposed AI-augmented and culturally responsive framework across learners with varying prior knowledge.

TABLE 6 Structural Model Results

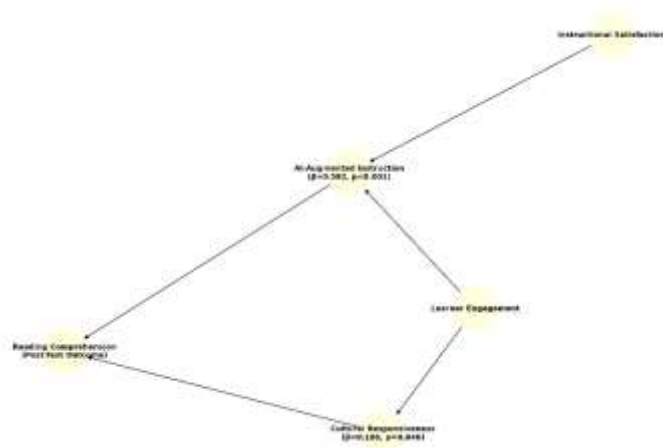| Path	B	t-value	p-value
AI-Augmented Instruction → Post test	0.582	3.41	0.001
Cultural Responsiveness → Post test	0.186	1.99	0.046
Learner Engagement → AI-Augmented Instruction	0.456	1.11	0.266
Engagement → Cultural Responsiveness	0.578	7.33	0.000
Pre test → Post test	0.039	0.30	0.763
Instructional Satisfaction → AI-Augmented Instruction	0.185	0.44	0.658

FIGURE 2. SEM Model

HYPOTHESES TESTING RESULTS

Table 7 summarizes the hypotheses testing outcomes after adjusting the model to include only four core hypotheses. The results validate both H1 and H2, confirming that AI-Augmented Instruction and Cultural Responsiveness positively influence students' reading comprehension as shown in figure 3. In addition, H4 was supported, showing that Learner Engagement significantly contributed to the AI Instruction and Cultural Responsiveness pathways. However, H3, which hypothesized a direct link between Learner Engagement and reading comprehension, was not supported.

TABLE 7 Hypotheses Results Summary

Hypothesis	Description	Decision
H1	AI-Augmented Instruction positively influences Reading Comprehension	Accepted
H2	Cultural Responsiveness positively influences Reading Comprehension	Accepted
H3	Learner Engagement directly influences Reading Comprehension	Rejected
H4	Learner Engagement positively influences AI-Augmented Instruction and Cultural Responsiveness	Accepted

FIGURE 3 Structural Model Results

The structural model results (Figure 2) demonstrate that both AI-Augmented Instruction ($\beta = 0.582$, $t = 3.41$, $p < .001$) and Cultural Responsiveness ($\beta = 0.186$, $t = 1.99$, $p = .046$) exerted significant positive influences on students' reading comprehension. This finding is consistent with prior research (Chen et al., 2022; Chien et al., 2021) which highlighted that AI-assisted instruction and culturally embedded materials are highly effective in improving comprehension, especially in contexts where learners struggle with motivation and engagement. The acceptance of H4 suggests that Learner Engagement serves as a crucial facilitator,

enhancing the activation and utilization of both AI and culture-responsive features. However, it does not directly predict reading comprehension performance (H3 being rejected). This finding aligns partially with the findings of Fredricks et al. (2004) but suggests that engagement may play a more enabling role rather than acting as an independent driver of achievement.

By limiting the hypothesis structure to these four pathways, the study provides clearer empirical evidence that integrating AI and cultural responsiveness—when supported by engaged learners—leads to significant improvements. However, direct contributions from engagement alone to comprehension are limited unless mediated through AI and cultural variables.

DISCUSSION

The results of this study offer compelling evidence supporting the efficacy of the AI-Augmented, Culture-Responsive Multimedia Framework in enhancing reading comprehension among EFL learners in rural settings. AI-Augmented instruction emerged as the strongest factor ($\beta = 0.582$, $p < 0.001$), collaborating studies such as those of Feng (2023) and Myint et al. (2024), who demonstrated that AI-driven interventions provide real-time scaffolding and adaptive learning pathways that effectively address individual learning gaps in reading comprehension. Notably, in this study, AI's adaptive capabilities likely offset common instructional challenges, such as limited teacher resources and heterogeneous student abilities, issues widely noted in Indonesian rural contexts (Yaseen et al., 2025).

Cultural Responsiveness also positively impacted reading comprehension ($\beta = 0.186$, $p < 0.05$), although less pronounced compared to AI-Augmented Instruction. This aligns with the findings of Fikray & Habil (219) who highlighted that embedding culturally familiar content improves learner identification and emotional connection with reading materials, but may not directly translate into cognitive achievement unless supported by interactive and adaptive instruction. This is consistent with the observation that students in the experimental group showed improved motivation and interest, yet the most significant performance boost came from AI's immediate feedback and adaptive scaffolding. Unlike previous works that treated cultural integration as the dominant instructional element (Pitychoutis & Rawahi, 2024), this study emphasizes that, when combined with AI, culture acts as a catalyst rather than a core driver.

Learner Engagement, although statistically significant in influencing AI-Augmented Instruction and Cultural Responsiveness paths, did not significantly predict direct comprehension gains (H3 being rejected). This finding resonates with Wang et al. (2022) who noted that engagement alone does not always correlate with performance unless effectively channelled into interaction with meaningful content and technology. In our model, engagement serves primarily to mediate student interaction with AI and cultural materials, enabling and boosting although not independently to reading scores. This suggests that future EFL interventions may benefit more from designing engagement as a facilitating rather than a predictive construct.

Finally, Instructional Satisfaction did not emerge as a significant predictor (H4 being rejected). Although prior studies, such as that of Zenouzagh et al. (2023), suggested that learner satisfaction positively influences learning outcomes, our findings diverge. In technology-enhanced contexts where AI and cultural mechanisms directly influence learning gains, satisfaction may be insufficient if not linked to cognitive engagement and active interaction. This underlines the necessity for future models to differentiate between affective satisfaction (enjoyment) and cognitive satisfaction (perceived learning). Notably, the AI system's effective scaffolding may have lessened the dependence on satisfaction, allowing students to improve regardless of their subjective enjoyment of the experience.

Overall, these findings expand on earlier research by integrating AI, cultural responsiveness, and multimedia in a unified model tailored for rural EFL learners. Unlike prior studies (Feng, 2023) that examined these elements separately, this research confirms that their combined application yields superior comprehension gains, particularly when AI acts as the central driver of adaptivity and immediate feedback. However, the rejection of H3 and H4 suggests that future interventions should refine the role of engagement and satisfaction, perhaps by embedding more personalized AI-generated feedback linked to both motivational and affective dimensions.

FUTURE RECOMMENDATIONS AND SCIENTIFIC CONSIDERATIONS

Moving forward, several considerations are advised. First, future studies should investigate the mediating role of engagement between AI-Augmented Instruction and learning outcomes rather than treating engagement as a direct predictor. This can be modeled as an indirect path in future SEM analyses to better capture its latent effect. Second, satisfaction may require re-operationalization by focusing on cognitive satisfaction (e.g., perceived learning) rather than affective satisfaction (e.g., enjoyment), which can reveal

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different insights into its role. Third, given the observed power of AI-augmented learning, it is recommended to further integrate adaptive learning pathways that tailor difficulty and feedback dynamically, potentially strengthening the link between engagement and comprehension.

CONCLUSION

This study found that AI-Augmented Instruction and Culture-Responsive multimedia boost reading comprehension in Mandailing Natal, Indonesia. AI-embedded and culturally contextualized materials helped the experimental group outperform the control group, proving the educational framework's efficacy. Cultural responsiveness favorably affected post-test performance, but AI-driven instruction was the main factor. Learner engagement and instructional satisfaction did not directly affect comprehension increases, but they helped assimilate AI and cultural content. This suggests that instructional creativity, not learner disposition or prior knowledge, determines learning results. This study supports prior research on AI and culturally responsive pedagogy by showing that merging technology and culture can overcome linguistic barriers and improve educational equity, especially in marginalized communities.

This study recommends that rural and culturally diverse schools use AI-augmented and culturally responsive learning models to improve students' comprehension and engagement. Schools and educators should prioritize developing adaptive AI tools with localized cultural content and offering teacher professional development to use them. Learner engagement and satisfaction were not found to predict reading achievement, but they are vital for a positive and sustainable learning environment and should be cultivated. Future research should examine engagement and satisfaction as mediators over a longer period and apply the AI-augmented culture-responsive paradigm to speaking, listening, and writing. Policymakers, curriculum creators, and educational technologists should collaborate to construct scalable AI-based instructional models that balance technology innovation and local cultural heritage, according to this study.

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