



ENHANCING PRIMARY STUDENTS' READING SKILLS THROUGH AUGMENTED REALITY-ENRICHED TURKISH TEXTS

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Abstract

The present study examined whether the integration of augmented reality (AR) into fourth-grade Turkish reading lessons enhances students' reading comprehension and motivation. A quasi-experimental pretest-posttest control group design was employed, involving 48 students (24 experimental and 24 control) from a public primary school. Students in the experimental group engaged with AR-enriched texts, while the control group read the same texts without AR enhancement. Reading comprehension proficiency and attitudes toward AR were measured using standardized scales, and qualitative interviews were conducted to gather student feedback. Results indicated that the experimental group demonstrated a significant improvement in reading skill scores compared to their baseline, while the control group showed no significant progress. A moderate positive correlation was observed between students' reading comprehension self-efficacy and their attitudes towards AR, indicating that students who felt more confident in their reading skills also tended to view AR-based learning more positively. Qualitative findings further revealed that AR enriched texts increased student engagement—evoking curiosity, excitement, and enjoyment—and helped students maintain focus during reading. These results suggest that integrating AR into reading activities can enhance elementary students' reading abilities and motivation. These findings highlight the potential of integrating AR into literacy education to foster students' engagement and comprehension. The study underscores the importance of designing technology-supported reading activities that align with curriculum goals and suggests that AR can serve as an effective educational tool to enhance motivation and learning outcomes in primary education.

Keywords: augmented reality, reading skills, primary education, educational technology

Introduction

Technological transformation in education has fundamentally altered pedagogical approaches and learning experiences worldwide. At the forefront of this transformation, Augmented Reality (AR) technology presents significant opportunities for enhancing educational outcomes by overlaying digital elements onto real-world environments. AR provides interactive and visually enriched learning experiences that can help students conceptualize abstract ideas and complex concepts (Azuma, 2004; Billinghurst & Duenser, 2012).

Research demonstrates that AR integration in classroom settings can facilitate students' comprehension of challenging content by creating more immersive and engaging learning environments (Kaufmann & Schmalstieg, 2002; Kerawalla et al., 2006). The implementation of AR technology in educational contexts yields multifaceted benefits, including increased student motivation and the establishment of high-quality learning environments that promote learner-centered, experiential education (Bower et al., 2014; Dunston et al., 2002).

However, AR integration presents certain challenges that warrant careful consideration. Limited device accessibility can exacerbate educational inequities, while excessive reliance on technology may adversely affect learners' real-world skill development and social interactions if not properly monitored (Labhane et al., 2024). Consequently, effective AR implementation in educational contexts requires a balanced approach that maximizes technological advantages while mitigating potential risks.

Recent empirical research in educational technology has highlighted the promising role of augmented reality in literacy education. Conventional approaches to reading pedagogy have increasingly incorporated multimedia elements to enhance engagement, with AR representing a significant advancement in integrating digital content with textual materials. Multiple studies have examined AR's effect on reading comprehension, yielding predominantly positive outcomes.

Çetinkaya Özdemir and Akyol (2021) conducted a quasi-experimental study with 54 primary school students, demonstrating that participants using AR-enhanced reading materials significantly outperformed the control group in reading comprehension assessments. Their findings underscore AR's capacity to support textual understanding by providing contextual cues and interactive elements directly embedded within reading materials. Similarly, Batdı and Talan (2019) reported that primary school students using AR applications during reading showed significant improvements in both comprehension and summarization skills compared to peers working with conventional textbooks, highlighting AR's effectiveness in fostering higher-order literacy abilities. Within the Turkish educational context, research by Zeybek and Sayın (2022) has provided particularly relevant insights. Their study on AR-based reading practices in primary school settings revealed notable improvements in terms of students' reading comprehension and motivation. The AR intervention transformed reading sessions into more interactive and gamified experiences, significantly increasing student enthusiasm for literacy tasks. These findings align with international research and provide evidence for AR's cross-linguistic effectiveness.

Meta-analytic studies have consolidated evidence supporting AR's educational benefits. Şimşek and Direkçi (2023) conducted a systematic review and meta-analysis examining AR's effects on reading practices, concluding that AR technologies have a significant positive impact on students' reading comprehension and reading speed. They attributed these improvements to AR's capacity to present information through multiple modalities (textual, auditory, and visual), facilitating more effective information processing and retention.

Garzón et al. (2019) have conducted a comprehensive meta-analysis on AR applications in education, identifying consistent improvements in learning outcomes, with reading comprehension showing particularly substantial benefits when AR was used as a supplementary educational tool. The authors attribute these gains to enhanced student engagement and the interactive feedback mechanisms inherent in AR applications.

Motivational factors represent critical components in reading development, and AR demonstrates considerable influence on these affective domains. Alsowat (2017) examined the effect of AR on English as a Foreign Language (EFL) reading and found that participants in the AR group not only achieved higher comprehension scores but also reported significantly greater interest and motivation compared to their non-AR counterparts. The interactive elements of AR, including animations and responsive feedback, can transform reading from a passive activity into an active exploration process, thereby enhancing student motivation.

While literature predominantly supports AR implementation, it also provides important considerations for effective integration. The pedagogical design of AR content proves crucial; merely adding digital elements to texts does not guarantee improved learning outcomes. Content must be pedagogically meaningful and aligned with specific learning objectives. Bursali and Yilmaz (2019) argued that AR features should complement and reinforce reading strategies

rather than distract from textual content. Their research indicates that when AR features directly relate to text (such as vocabulary support or story element visualization), reading comprehension improves, while extraneous or overly complex AR features may cause cognitive overload.

Current research provides compelling evidence that AR can enhance reading comprehension, engagement, and motivation among primary and secondary students. AR's ability to create multimodal learning environments appears particularly beneficial for learners who struggle with traditional text-only materials. These findings establish a solid foundation for future research exploring AR's potential in literacy education across diverse linguistic and cultural contexts, while emphasizing the importance of thoughtful pedagogical integration to maximize educational benefits.

Research Problem

Conventional approaches to developing reading skills, particularly in primary education, may not fully engage today's digitally oriented learners. Challenges such as declining motivation to read and difficulties in comprehending text can potentially be addressed through innovative educational strategies. Augmented Reality (AR) offers a novel way to enrich reading materials with interactive features, which may help capture students' attention and enhance comprehension. The research problem focuses on whether integrating AR into reading materials can meaningfully improve primary school students' reading skills and overall learning experience.

Research Focus

This study focuses on the intersection of technology and literacy education. Specifically, it examines augmented reality as an educational tool in primary-level Turkish language classes, exploring its effects on students' reading comprehension skills and learning motivation. The content area of focus is Turkish reading texts for fourth-grade students, enriched with AR elements such as 3D visuals and audio to create an interactive reading environment.

Research Aim and Research Questions

The main purpose of the research was to evaluate the effect of AR-enriched texts on improving primary school students' reading skills. In line with this aim, the study addressed the following research questions:

- 1) Does the use of AR-enriched texts in Turkish language lessons lead to significant improvements in fourth-grade students' reading comprehension compared to standard printed (non-AR) texts?
- 2) What is the correlation between students' reading comprehension proficiency and their attitudes towards the use of AR technology in learning?
- 3) How do students experience reading AR-enriched texts with respect to their engagement, motivation, and the challenges they encounter during the process?

By addressing these questions, the study aimed to demonstrate the potential of AR to enhance literacy education and to offer practical guidance for educators considering the integration of AR technologies into their teaching practices.

Research Methodology

Design

This research employed a mixed-methods, quasi-experimental design to investigate the effects of AR-enriched texts on students' reading skills. The quantitative component followed a pretest–posttest control group design, while the qualitative component involved interviews to capture student perceptions. A quasi-experimental approach was chosen due to the classroom setting, where random assignment of students to separate groups was not feasible; instead, existing class sections were designated as experimental and control groups. While intact classes were used, pre-existing differences (e.g., student motivation, teacher–student dynamics) may still have influenced the outcomes. To address this, pretests were administered, and the analyses showed no significant baseline differences between groups, supporting the internal validity of the comparisons. The study was conducted in the natural setting of a single primary school to preserve ecological validity, which also represents a limitation in terms of generalizing the findings. Both quantitative and qualitative data were collected in parallel, allowing for triangulation of findings to better understand the effect of the AR intervention. This methodology aimed to isolate the effect of the AR-enriched texts by comparing outcomes between students who used the AR materials and those who engaged with conventional reading activities using identical texts without the AR features. Ethical considerations, including informed consent from parents and assent from the students, were observed, and the school administration approved the implementation of the AR activities as part of the research, which was conducted between April 3 and May 21, 2023.

Study Group

The study group consisted of 48 fourth-grade students (approximately 9–10 years old) from a public primary school located in the Alaplı district of Zonguldak province in northwestern Turkey. These students were divided into two groups: an experimental group ($n = 24$) and a control group ($n = 24$). The grouping was done by class: one intact fourth-grade class was assigned as the experimental group, and another as the control, ensuring that normal classroom dynamics were maintained. Both groups were equivalent in terms of age, grade level, and prior academic performance based on school records and a preliminary reading skill assessment conducted with the Reading Comprehension Proficiency Scale, a curriculum-based test aligned with fourth-grade standards. A pretest confirmed that there were no statistically significant differences between the groups' baseline reading comprehension levels ($t = 1.266$, $p = .212$). The school was located in an urban area and was equipped with a computer lab and tablet devices, which facilitated the deployment of the AR application for the experimental group. All participating students had a basic familiarity with touchscreen devices (such as tablets or smartphones), but none had prior experience with educational AR applications. This ensured that any improvements observed could be attributed to the AR intervention rather than pre-existing differences in technology use. The relatively small sample size was a consequence of working with intact classrooms; however, it was considered sufficient to detect medium-to-large effects based on Cohen's (1988) guidelines for educational research and the controlled nature of the design. The study acknowledges that the sample, although representative of the school's student population, may not fully capture the diversity of socio-economic or regional backgrounds, which is considered when generalizing the results.

Data Collection Tools and Procedures

Three main instruments were used to collect data. First, a Reading Comprehension Proficiency Scale was administered to assess students' reading skills. This scale was a curriculum-based test tailored to fourth-grade reading competencies, measuring skills such as understanding main ideas, making inferences, and summarizing. It was developed and validated in prior research to align with the Turkish language curriculum's standards for reading proficiency. The internal reliability of this scale in the present study was high (Cronbach's $\alpha = .835$ for the pretest and $.909$ for the posttest), indicating consistent performance. Second, students' attitudes toward AR were measured by the Augmented Reality Applications Attitude Scale developed by Küçük et al. (2014). This Likert-type scale includes items that gauge students' interest, perceived usefulness, and comfort with AR technology in learning contexts. It was administered only to the experimental group (who had exposure to AR) at the end of the intervention. In our sample, the attitude scale demonstrated good reliability ($\alpha = .83$), which is considered acceptable for educational research (Nunnally & Bernstein, 1994). Third, a Semi-Structured Interview Form was designed to collect qualitative data on student experiences. This form was developed in consultation with three educational technology experts and included four open-ended questions focusing on the students' feelings about reading with AR, the perceived advantages or difficulties, and suggestions for improvement. The number of questions was intentionally limited to four to accommodate the age group and ensure that primary school students could respond without experiencing fatigue or loss of attention. The interview protocol covered key topics, such as engagement levels, motivation, perceived learning, and any technical challenges encountered during the AR sessions.

The experimental treatment was built around a set of augmented reality-enriched texts. Four texts were carefully selected from the official fourth-grade Turkish language textbook used in the national curriculum, representing a range of genres: two informational texts, one narrative story, and one poem. These texts were chosen with input from subject matter experts to ensure they were age-appropriate and representative of the curriculum's reading material. Each selected text was augmented using AR technology. The development of AR content was accomplished with *Unity* 3D game engine and the *Vuforia* AR platform. For each text, relevant 3D objects, animations, or audio were created or sourced (e.g., a 3D model of a character or object mentioned in the text, or an audio narration for a poem) to complement the content of the reading passage. These AR elements were carefully aligned with the educational objectives of the text – for instance, an informational text about the solar system included AR planets that students could tap for additional facts, while the narrative story featured an AR character animation to help visualize the plot. The design of AR materials followed multimedia learning principles to avoid cognitive overload; thus, each AR element was directly related to key content in the text and was intended to reinforce comprehension rather than distract. The AR content was reviewed by three experts (a Turkish language educator, an educational technologist, and a literacy curriculum specialist) who provided feedback on its pedagogical appropriateness. Their feedback led to minor revisions to ensure that the AR elements were supportive of learning (e.g., adjusting the placement of AR triggers on the page, clarifying the guidance provided to students). During the intervention, the experimental group used tablets to interact with the AR-enriched texts. A custom AR mobile application was developed and installed on the tablets; when students pointed the tablet's camera at the textbook page, the app recognized images (via *Vuforia* image tracking) and displayed the corresponding AR content on-screen. Each student in the experimental group had access to a tablet during reading lessons. The teacher provided a brief demonstration to the experimental group on how to use the AR app at the start of the intervention, ensuring that students understood how to trigger and interact with the AR features (e.g., hovering over images, tapping on 3D models for information). The control group,

in contrast, worked with the same four texts in their standard printed form, without digital enhancements. They engaged in standard classroom reading practices: reading the texts on paper and participating in teacher-led discussions and comprehension exercises.

The study was carried out over a four-week period between April 3 and May 21, 2023, during regularly scheduled Turkish language lessons. In Week 1, all students took the reading comprehension pretest. Following the pretest, the experimental group was introduced to the AR reading app and given time to familiarize themselves with one sample AR exercise unrelated to the study texts, to practice the mechanics of using the AR features. From Weeks 1 to 3, the intervention was implemented: each week, both groups read one of the selected texts during class. The experimental group read the AR-enriched version of the text – typically, they would read a segment of the text in their textbook and then use the tablet to view AR content connected to that segment. For example, while reading a story, they could see an AR illustration of the scene or hear character dialogue via the app. The teacher in the experimental class integrated prompts to guide students' attention between the text and AR features (for instance, "After reading this paragraph, use the tablet to explore the 3D model of the character and describe what you see"). Meanwhile, the control group read the same text without any AR, following the usual pedagogical routine (such as silent reading followed by teacher questions and class discussion). Both groups spent roughly equal time on each text (about two class periods per text). The teacher was careful to cover the same content and ask similar comprehension questions in both classes to ensure that the only substantive difference was the presence of AR. It should be noted that while the control group had no AR content, they were not deprived of engagement – the teacher used pictures and questions as normally done, but these were static and from the textbook, rather than interactive.

In Week 4, after all texts were covered, the posttest reading comprehension assessment was administered to both groups under identical conditions to measure learning gains. Additionally, the AR Attitude Scale was given to the experimental group to quantify their receptiveness to the AR learning experience. On the qualitative side, shortly after the posttest, one-on-one interviews were conducted with a subset of students (12 from the experimental group and, for comparison, 6 from the control group). Each interview lasted about 10–15 minutes. For experimental students, questions probed their experience with AR: e.g., "What did you like or not like about reading with augmented reality?" and "Do you think the AR features helped you understand the story better? Why or why not?" For control students, questions focused on their experience with the texts and any difficulties, serving as a secondary comparison for student engagement levels. All interviews with experimental group students were audio-recorded and later transcribed for analysis. The interview with control students aimed to ensure that any differences in engagement noted in the experimental group were indeed due to AR and not some other factor; these students were asked if they found the texts interesting and what could have made the reading more engaging, often yielding responses that implicitly highlighted the absence of interactivity in their reading sessions.

Data Analysis

The data analysis strategy employed both quantitative and qualitative approaches to comprehensively evaluate the effects of AR-enriched texts on students' reading comprehension.

For the quantitative analysis, descriptive statistics were computed for all variables, including means and standard deviations for pretest and posttest scores. Assumptions of normality were examined using the Shapiro–Wilk test, and homogeneity of variances was verified with Levene's test. Since these assumptions were satisfied, parametric procedures were applied. To address the first research question, paired-samples t-tests were conducted within each group to examine pretest–posttest changes. Independent-samples t-tests were employed

to compare posttest performance between the experimental and control groups. Effect sizes were calculated using Cohen's d in order to assess the practical significance of the findings. To address the second research question, Pearson product-moment correlations were conducted to examine the association between reading proficiency and attitudes toward AR. All quantitative analyses were performed using IBM SPSS Statistics (Version 25), with the significance threshold set at $\alpha = .05$.

For the qualitative analysis, transcribed student interviews were examined using inductive content analysis following the procedures described by Elo and Kyngäs (2008). This approach allowed themes to emerge directly from the data without the imposition of predefined categories. Two independent researchers coded the transcripts, and inter-rater reliability was established through discussion and consensus on discrepancies. The emergent themes were subsequently compared with the quantitative results to ensure methodological triangulation and to provide deeper insights into the mechanisms underlying the observed improvements. Five major thematic categories were identified: (1) Increased Engagement and Enjoyment, (2) Enhanced Comprehension Support, (3) Focus and Attention, (4) Technical Challenges, and (5) Suggestions for Improvement.

Research Results

Reading Skill Improvement

The findings showed a significant improvement in reading comprehension for students who engaged with AR-enriched Turkish texts. As indicated by the paired-samples t -test results (Table 1), the experimental group's mean reading comprehension score increased markedly from pretest ($M = 11.95$, $SD = 2.44$) to posttest ($M = 16.45$, $SD = 1.85$), while the control group's performance remained statistically unchanged. These gains were not only statistically significant but also meaningful in terms of educational effect, as the experimental group demonstrated enhanced abilities in summarizing, interpreting, and inferring textual information.

Table 1

Comparison of Correct Answer Scores between Experimental and Control Groups

Group	Pretest M	SD	Posttest M	SD	t	p	Cohen's d
Experimental (n=24)	11.95	2.44	16.45	1.85	7.62	< .001	1.56
Control (n=24)	11.91	2.13	12.54	2.27	1.12	> .05	0.23

In Table 1, paired-samples t -test results indicated a significant improvement in the experimental group with a large effect size ($d = 1.56$), while the control group showed no significant change ($d = 0.23$).

Table 2
Comparison of Reading Skills Between Experimental and Control Groups (Posttest)

Group	Posttest <i>M</i>	<i>SD</i>	<i>t</i>	<i>p</i>	Cohen's <i>d</i>
Experimental (n=24)	16.45	1.85	4.35	< .001	1.89
Control (n=24)	12.54	2.27			

When comparing the two groups post-intervention, the independent-samples *t*-test results show that the experimental group significantly outperformed the control group ($p < .001$), with a large effect size (Cohen's $d = 1.89$). This finding supports the hypothesis that AR integration has a positive effect on reading skills in primary school students, particularly by offering visual and interactive support that scaffolds learners' understanding of complex or abstract textual content.

Furthermore, higher-order reading skills such as predicting outcomes and making inferences were better developed in the experimental group. These improvements can be attributed to the multimodal nature of AR content, which helped students visualize, hear, and process information more effectively. For instance, students were better able to recall story events, understand figurative language, and apply context clues to derive word meanings.

Attitudes and Engagement

The attitude data indicated a strong positive reception of AR among students in the experimental group. Descriptive statistics from the AR Attitude Scale are presented in Table 3.

Table 3
Descriptive Statistics of AR Attitude Scale (Experimental Group)

Dimension	<i>M</i>	<i>SD</i>
Enjoyment	4.42	0.53
Willingness to Use	4.36	0.59
Usage Anxiety	1.28	0.47
Overall Attitude	4.30	0.48

Students rated their enjoyment and willingness to use AR in the future highly, while their anxiety levels remained low. The moderate positive correlation ($r = .45$) between attitude scores and reading performance is shown in Table 4 and underscores the motivational potential of AR. This finding suggests that AR not only enhances learning outcomes but also increases students' willingness to engage with reading tasks.

Table 4*Correlation Between AR Attitudes and Reading Comprehension Proficiency*

Measure	Correlation (<i>r</i>)	<i>p</i>
Posttest Reading Score & AR Attitude Score	.45	< .05

A moderate positive correlation ($r = .45, p < .05$) was found between students' attitudes toward AR and their reading comprehension performance. This suggests that more favorable attitudes toward AR were associated with higher reading scores; however, this relationship is correlational and does not imply causation.

Qualitative Findings from Student Interviews

The interview data provided rich, contextual evidence that supported the quantitative findings, shedding light on how augmented reality (AR) transformed students' reading experiences. Participants from the experimental group consistently described the AR-based reading activities as immersive, engaging, and highly stimulating. Many students expressed that the stories "came to life" through the dynamic visual and auditory elements, which not only captured their interest but also enhanced their ability to visualize and internalize the content. One student enthusiastically stated, "*When the AR animation started, it felt like I was watching a movie made from the book. It made the story real for me, and I didn't want to stop reading.*" Another remarked, "*I usually get distracted after a few minutes, but AR made me curious about what would happen next, so I kept reading without getting bored.*"

This heightened engagement manifested in longer periods of focused attention and a greater willingness to complete reading tasks. Students referred to the AR components as "checkpoints" or "rewards" that motivated them to continue reading attentively. One student commented, "*I read more carefully because I knew something would appear—an animation or sound—if I understood the part correctly. It was like a game that helped me focus.*" These reflections suggest that AR features served not only as motivational tools but also as embedded comprehension scaffolds, encouraging deep processing of the text.

In addition to engagement, students highlighted how the multimodal AR elements facilitated comprehension. For example, visual reconstructions of historical sites or events helped students better understand descriptive passages in informational texts. One student explained, "*When I saw the ancient building in 3D, I understood its shape and parts much better than just reading the description.*" Similarly, the AR-read-aloud function in literary texts enhanced students' understanding of tone, rhythm, and emotional nuance, which are often difficult to grasp through silent reading. "*When I heard the poem read aloud with the right emotion, I felt what the poet was saying,*" a student reflected, pointing to AR's role in supporting both cognitive and affective aspects of reading.

Despite the generally positive feedback, some students encountered technical issues at the beginning of the intervention, such as difficulty aligning the tablet camera with the AR markers or brief delays in content loading. These minor frustrations, however, diminished over time with teacher guidance and increased familiarity. Teachers provided troubleshooting strategies, including optimal device positioning and patience during app loading. By the second week, nearly all students reported using the AR features independently and smoothly. Importantly, even those who experienced technical difficulties expressed continued enthusiasm for the AR-enhanced readings, indicating that the educational benefits and novelty of the experience outweighed any initial setbacks.

In contrast, students in the control group reported more neutral or indifferent attitudes toward their reading lessons. Their comments often reflected a lack of excitement or emotional engagement. Typical responses included statements such as, *"It was just normal reading,"* or *"Sometimes I lost interest when the story was long."* Some admitted they skipped parts of the texts when they felt tired or bored, which may partially explain the comparatively lower comprehension scores observed in the quantitative analysis. The absence of interactive or sensory stimuli in the control group's reading experience appeared to limit their sustained attention and intrinsic motivation.

These contrasting accounts between the experimental and control groups reinforce the conclusion that AR not only enhances cognitive learning outcomes, such as reading comprehension and vocabulary acquisition, but also transforms the affective and motivational dimensions of the learning experience. The qualitative findings suggest that AR's multimodal affordances—through visual, auditory, and interactive content—can promote deeper engagement, increased comprehension, and greater learner autonomy, particularly when thoughtfully integrated into literacy education and supported by curriculum-aligned reading activities.

Discussion

The findings of this study align with and extend the growing body of literature on augmented reality (AR) in education. In particular, the significant improvement in reading comprehension observed in the AR-enriched group (Cohen's $d = 1.56$) highlights AR's potential as an effective educational tool for literacy development. This large effect size is consistent with those reported in prior empirical studies and recent meta-analyses, thereby reinforcing the robustness of the current results. For example, Çetinkaya Özdemir and Akyol (2021) reported enhanced comprehension in elementary students using AR, while Zeybek and Sayın (2022) and Bursali and Yilmaz (2019) found gains in both comprehension and motivation with AR-based reading activities. At an international level, Garzón et al. (2019) conducted a meta-analysis showing consistent positive effects of AR on learning outcomes, particularly in reading comprehension when AR was integrated as a supplementary support. Similarly, Zhang et al. (2022) and Na and Yun (2024) reported large effect sizes for AR in K–12 contexts, underscoring its value for improving both achievement and motivation. By demonstrating the effect of AR-enriched texts in a Turkish primary education context, this study contributes additional evidence that AR's benefits for reading are not confined to a single language or curriculum but may be generalizable across diverse educational settings. In doing so, it also reflects ongoing discussions in the journal about the integration of innovative educational technologies and the importance of infrastructure, teacher preparedness, and equitable access (Durso & Arruda, 2022).

The substantial gains in the experimental group's ability to summarize and recall information indicate that AR supports not only literal comprehension but also higher-order thinking skills. A plausible explanation is that AR's interactive and multimodal presentation reinforces cognitive processing, in line with dual-coding theory, where information presented both visually and verbally creates stronger memory traces. In the AR condition, students simultaneously heard, saw, and read content, engaging multiple senses, which likely facilitated deeper processing and better retention, as reflected in their performance and feedback. Similar multimodal benefits of AR have been highlighted in international studies (e.g., Garzón et al., 2019; Radu, 2014; Vidak et al., 2023), reinforcing the view that AR's strength lies in combining visual, auditory, and textual input in a cohesive learning experience.

The positive attitudes toward AR and the moderate correlation between attitudes and reading performance are also noteworthy. This suggests a reciprocal relationship where engaging educational methods promote both enjoyment and achievement, which in turn further

motivates learners. These findings align with motivational frameworks, such as the ARCS model (Attention, Relevance, Confidence, Satisfaction). In this study, AR clearly captured students' attention and provided relevance by linking interactive content directly to lesson objectives. Qualitative data add depth to this result by revealing that students perceived AR reading sessions as exploratory and playful rather than obligatory tasks, echoing findings from Alsowat (2017) and Bursali and Yilmaz (2019), showing that AR can increase both engagement and comprehension by making reading more interactive and enjoyable. This is also consistent with Na and Yun's (2024) meta-analysis, which shows AR's strong motivational effects in K–12 students.

A further contribution of this study lies in highlighting AR's potential as an embedded scaffold for comprehension. Students frequently reported that AR content helped clarify or visualize what they read. This aligns with Vygotsky's concept of the Zone of Proximal Development (ZPD), as AR acted as just-in-time support, enabling learners to achieve a higher level of comprehension than they might with text alone. The immediacy and availability of these supports distinguish AR from static media, suggesting that integrating multimodal cues directly into the reading process can facilitate independent learning. These findings extend the work of Radu (2014), Garzón et al. (2019), and Nevrelova et al. (2024), offering additional evidence of AR's capacity to provide embedded scaffolding that enhances both comprehension and learner autonomy.

In addition to cognitive outcomes, the findings suggest AR may foster metacognitive skills. Several students reported paying closer attention to details in anticipation of AR content and described strategies such as previewing and revisiting passages to connect text with interactive elements. These behaviors reflect metacognitive monitoring and active reading strategies, which are critical in developing literacy. This extends current research by suggesting that AR's novelty and interactivity can prompt students to engage in deeper, self-regulated learning behaviors, offering an avenue for future longitudinal studies to explore whether such strategies persist beyond the AR environment.

While the findings indicate a generally positive effect of AR, limitations must be acknowledged. The quasi-experimental design using intact classes introduces potential biases, as random assignment was not feasible. Pre-existing differences between the two classes (e.g., teacher dynamics, classroom culture, peer interactions) could have influenced the results, despite pretest equivalence. The experimental and control groups were taught by the same teacher to minimize teacher effects, but subtle differences in implementation or enthusiasm could still have occurred. Additionally, the study was relatively short-term (one month) and employed a controlled set of texts, providing proof-of-concept rather than evidence of long-term outcomes. It remains to be seen whether the observed gains would sustain over an academic year or whether the novelty effect would diminish over time. These questions point to the need for longitudinal research examining sustained AR integration and teacher-led implementations in real classroom contexts. Although technical issues were minimal in this study, they underscore the importance of reliable infrastructure and teacher training for scaling AR in diverse educational settings.

The findings also carry implications for curriculum design and policy. The positive outcomes highlight the potential for integrating AR components into reading materials, particularly for content students often find challenging or less engaging, such as classical literature or dense informational texts. By embedding multimodal support within curriculum-aligned materials, AR can help create more adaptive and student-centered literacy experiences. Furthermore, as digital literacy becomes increasingly vital, AR-based reading activities not only strengthen traditional literacy but also prepare students to navigate multimodal texts, a key competency in 21st-century education (Nevrelova et al., 2024). However, successful implementation requires professional development to help teachers facilitate AR-based learning effectively and to balance student-led exploration with structured teacher guidance.

Overall, the study provides new evidence that AR, when thoughtfully designed and aligned with educational objectives, holds promise for enhancing both cognitive and motivational aspects of literacy learning. The results demonstrate that educational technology can address concrete classroom challenges, such as improving comprehension and engagement in reading. Moreover, the findings emphasize the importance of pedagogy-driven design in leveraging AR effectively and highlight avenues for extending this work into other subject areas and diverse learning environments. Ultimately, this research contributes to the evolving understanding of how AR can enhance literacy development and provides insights for integrating multimodal digital tools into curricula in culturally and linguistically responsive ways.

Conclusions and Implications

This study provides evidence that AR-enriched reading materials can meaningfully improve primary students' comprehension and motivation when thoughtfully integrated into curriculum-based activities. The results indicate that AR's multimodal features enhance literal understanding of texts and support higher-order skills such as inference and summarization, while also fostering more positive attitudes toward reading.

These findings carry several practical implications. Embedding AR components into reading materials - especially for content that students often find challenging - can make literacy experiences more engaging and effective. However, the design and implementation of such materials require careful pedagogical alignment, ensuring that technology supports, rather than overshadows, learning objectives. Teacher training remains essential for equipping educators with the skills to integrate AR effectively and manage classroom dynamics. At the curriculum and policy level, incorporating AR can contribute to the development of multimodal literacy, an increasingly relevant competency in contemporary education. Schools adopting AR should also consider infrastructure and equity issues to ensure broad access and sustained technical support.

Despite these promising results, the study has important limitations. The short-term intervention design limits conclusions about the durability of effects, and no direct measures of accessibility or metacognitive processes were included. While student reports indicated deeper engagement, further research is needed to examine whether AR systematically promotes metacognitive strategies. Future studies should investigate long-term outcomes, scalability across diverse learning contexts, and the design features of AR that best balance interactivity with cognitive load.

Taken together, the findings point to AR as a promising pedagogical tool that can enrich reading practices when integrated with sound educational objectives and supported by well-prepared teachers. Its potential should be understood within the boundaries of this study's design, with future research needed to clarify its broader applicability and sustainability.

Ethical Statement

All procedures performed in this study were in accordance with the ethical standards of the institutional and national research committee, as well as with the 1964 Declaration of Helsinki and its subsequent amendments. Ethical approval was obtained from the Ethics Committee of Zonguldak Bülent Ecevit University (Türkiye) under protocol number 380, dated November 30, 2022. Informed consent was obtained from all participants prior to data collection.

Declaration of Interest

The authors declare no competing interest.

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