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# Integrating augmented reality in EFL reading comprehension: a mixed-methods study

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**Abstract**

Reading comprehension presents persistent challenges for English as a Foreign Language (EFL) learners, yet augmented reality (AR) tools offer promising opportunities to augment reading support. This mixed-methods study investigated the efficacy of AR applications for improving reading comprehension among 98 intermediate-level EFL students (ages 22-36). It also explored six EFL teachers' perspectives on their use of AR in the classroom through semi-structured interviews. One-way ANCOVA was used to quantitively examine the effects of AR applications on learners' reading comprehension and thematic analysis was utilized to analyze the data of the interviews. The quantitative results showed the effectiveness of thoughtfully designed AR applications for enhancing EFL reading comprehension. The qualitative findings of the interviews indicated that teachers valued AR technology as an effective and beneficial tool for EFL learners. They recognized its potential for facilitating deep learning of language skills, enhancing learners' positive attitudes, and increasing their willingness to use AR-based approaches in EFL classes. However, teacher perspectives highlight the complexities and challenges of implementing emerging AR technologies in EFL contexts. The findings of the study called for adopting AR technology to enhance language learning experience, increase learners' engagement, and create a more favorable environment for language learning. Practical strategies for integrating AR in EFL contexts and pedagogical implications for reading comprehension are discussed.

**Keywords:** Augmented reality, Teacher's perspectives, Reading comprehension, AR apps

## Introduction

Reading comprehension is a crucial skill for language learners. However, many Iranian EFL students face challenges comprehending texts due to various factors, such as limited vocabulary, background knowledge, and motivation (Jafarigohar & Behrooznia, 2012; Khataee, 2018). According to Khataee (2018), some Iranian EFL students at the university

level struggle to understand texts in English. He argued that enhancing the students' reading comprehension skills would improve their academic achievement and motivation. It is essential to find effective ways to enhance EFL learners' reading comprehension skills and to foster their interest and engagement in reading to overcome these challenges. One possible way to achieve this goal is to use Augmented Reality (AR). This technology can create an immersive and interactive learning environment by integrating virtual objects into the physical world (Su et al., 2023). AR combines the physical world with digital content, providing an immersive experience of a real-world environment (Belda-Medina & Marrahi-Gomez, 2023). It enables learners to interact with information feedback in various formats, such as visual or tactile such as images, sounds, or texts, that can offer additional information or guidance for learners. AR will enable students to interact directly with scientific phenomena that may otherwise be difficult to observe by overlaying virtual models and simulations onto the real world (Radu et al., 2023). AR can provide rich and varied language input that can benefit learners with different styles and preferences (Chang et al., 2022).

AR has the potential to make English learning more interesting and engaging for students by incorporating gaming elements (Su et al., 2022). AR can provide feedback that can motivate continued learning by tracking student performance data through its applications (Su et al., 2022). By enhancing engagement and supporting understanding through multimedia supplementation of text, AR appears to improve measures of reading comprehension, like retelling and recalling story details, compared to print alone (Danaei et al., 2020). Şimşek and Direkçi (2023) found that AR enhances reading comprehension by engaging and motivating the learning process through enriched multimedia.

Danaei et al. (2020) highlighted that augmented reality (AR) can positively influence children's reading comprehension. They stated that multimedia elements supported through AR interfaces could help children understand complex concepts or events that are difficult to grasp from words alone. Mozaffari and Hamidi (2023) studied using augmented reality (AR) in foreign language teaching. They highlighted that AR is a powerful technology that merges virtual elements with the real environment, providing learners with a contextualized and immersive learning experience. Ebadi and Ashrafabadi (2022) indicated that AR applications significantly improved reading achievement and attitudes among Iranian EFL learners by providing interactive and immersive to stimulate their senses and interest. The literature lacks studies that compare AR reading interventions to traditional methods using rigorous research designs with Iranian EFL students across various proficiency levels. Moreover, there is a lack of studies that explore the teachers' perceptions of using AR tailored to Iranian EFL contexts classes and its impact on their teaching practices and students' learning outcomes.

By incorporating an innovative augmented reality application called "XR Plus" and a larger sample size, this study distinguishes itself from previous research. XR Plus empowers researchers to integrate visuals as supplementary aids to reading passages, thereby facilitating students' comprehension of complex texts and vocabularies. Utilizing the "XR Plus" app's capabilities, the study aims to provide a comprehensive learning experience that not only aids in reading comprehension but also fosters cognitive and metacognitive skill development. This study also used a theoretically grounded research design based on constructivist learning theory, which emphasizes the active role of learners in constructing knowledge through interaction with their environment and others. The application's advanced image tracking and interactive 3D objects provide an immersive learning environment that aligns with the constructivist approach, where learners actively construct knowledge through engagement and interaction. This study aimed to investigate the impacts of the XR Plus AR app, a tailored AR reading tool, on the reading comprehension performance of Iranian EFL elementary students. It examines how AR technology, aligned with constructivist principles, can enhance reading comprehension by providing interactive and multimodal texts. It also explored the teachers' perceptions of integrating the AR-based mobile applications in their language classes to highlight their benefits and challenges.

The following research questions guided this study:

1. What are the impacts of using the AR-based mobile applications on students' reading comprehension performance?
2. What are teachers' perceptions of integrating AR-based mobile applications in EFL classrooms? How does AR influence the teaching process?

## Literature review

### Reading comprehension

Reading comprehension is a complex process that involves using one's eyes, ears, and brain to see, comprehend, understand, and mentally generate meaning (Palani, 2021). According to Vygotsky and Cole (1978), reading is viewed as a social skill that requires active participation, interaction, and involvement of learners. Successful comprehension creates and maintains a coherent and reasonably accurate situation model (Radvansky, 1999). Reading comprehension is a complex and multifaceted skill that involves various cognitive processes, such as decoding, vocabulary, inference, metacognition, etc. Reading comprehension is also influenced by various factors, such as text characteristics, learner characteristics, task characteristics, etc. (Grabe, 2009).

EFL learners may face several challenges in reading comprehension, such as dealing with unknown vocabulary and rote memorization, boring content and lack of interest and

motivation, anxiety, lack of inferential skills, and practice time outside the classroom. Research has shown that mental visualization contributes to reading comprehension (Morrow et al., 1989; Perfetti & Stafura, 2014). Augmented reality (AR) technology is motivating and enjoyable for students (Billinghurst & Duenser, 2012) and can help reduce students' anxiety levels while doing reading activities and enhance word learning (Piriyasurawong, 2020). Research has shown clear benefits of using AR apps and digital texts for readers, especially when aligned with appropriate reading strategies (Huisinga, 2017).

## Augmented reality

Augmented reality (AR) is a technology that blends the real environment with virtual elements (Akçayir & Akçayir, 2017). It allows users to interact with digital information superimposed on the real world, creating a mixed-reality environment (Mystakidis et al., 2021). AR has been widely used in education to enhance students' motivation, engagement, and performance by providing immersive and interactive learning experiences (Chen et al., 2020). Moreover, AR can create authentic learning environments that are impossible in traditional classrooms, such as virtual laboratories, simulations, field trips, and games (Diegmann et al., 2015). Integrating AR into school curriculums to teach subjects like science, math, and history can promote active learning and student engagement (Ou Yang et al., 2023).

AR technology is a powerful tool that can enhance students' learning outcomes in various ways. It allows the integration of real and virtual worlds, providing a more enriched learning experience that can significantly improve knowledge retention. The immersive and interactive nature of AR stimulates students' cognitive processes and enhances their critical thinking skills (Alkhabra et al., 2023). AR has the potential to assist instructors in integrating real reading comprehension skills into lessons, including video modeling and individual practice (Shaaban & Mohamed, 2024). Sat et al. (2023) stated that AR technologies offered advantages such as "materializing abstract concepts, facilitating permanent learning, and catching student interest in interactive materials" when designing interactive course content. The collaborative nature of AR experiences allows multiple students to simultaneously interact with shared virtual content, thus fostering opportunities for peer collaboration (Akçayır & Akçayır, 2017).

AR has been used in various educational contexts, including reading comprehension, which is one of the essential skills for language learners. One of the ways that AR can be used to improve reading comprehension skills is by providing learners with interactive and multimodal texts that combine text, images, audio, video, and animations. This can help learners to engage with the text more deeply and to access different types of information that can support their comprehension (Chen et al., 2016). Another way is by creating

personalized and adaptive learning experiences that match the learners' needs, preferences, and levels. This can help learners to progress at their own pace and to receive immediate feedback and guidance that can enhance their comprehension (Chen et al., 2016).

Moreover, AR can enable learners to manipulate and explore virtual objects related to the text content. This can help learners to visualize and understand abstract or complex concepts and to apply their prior knowledge and experience to the text (Ibáñez et al., 2014). Furthermore, AR can foster collaborative and social learning among learners who can share their AR experiences and perspectives on the text.

## Theoretical framework

The study draws on constructivist learning theory as the main theoretical framework, which posits that learners construct knowledge through their active engagement with their environment and their interactions with others (Piaget, 1970; Vygotsky & Cole, 1978). Constructivist learning theory suggests that learners construct knowledge through active engagement with their environment and interactions with others (Piaget, 1970; Vygotsky & Cole, 1978). According to this theory, learning is not a passive process of receiving information from external sources but rather an active process of creating meaning from experience (Jonassen & Rohrer-Murphy, 1999). Constructivist learning theory implies that AR can enhance students' reading comprehension by providing interactive and multimodal texts that combine text, images, audio, video, and animations (Chen et al., 2016). AR can also enable students to manipulate and explore virtual objects related to the text content, which can help them deepen their understanding and retention of the information (Ibáñez et al., 2014).

## AR in reading comprehension

Augmented Reality (AR) is a novel technology that can improve reading comprehension and elementary students' engagement. According to Şimşek and Direkçi (2023), AR can increase students' engagement and motivation in reading activities. They suggested that AR features helped reduce cognitive load for readers by providing visual scaffolds, and context cues, and reducing abstraction which facilitated deeper comprehension, especially for complex or advanced material. Recent studies have revealed promising results regarding using augmented reality (AR) to improve reading comprehension. Shaaban and Mohamed (2024) found that using an AR-based mobile application significantly improved the reading comprehension skills of early childhood pupils with learning disabilities. They also found that the learners showed positive attitudes toward AR and enjoyed the interactive and multimodal texts provided by the application. Ebadi and Ashrafabadi (2022) found that using an AR-based mobile application significantly improved the reading comprehension skills of upper-intermediate university students. They also found that the

learners expressed high satisfaction, relevance, and reliability toward using AR and preferred it to traditional methods. Moreover, they found that the teachers valued AR as an effective and beneficial tool for language learning and teaching. Danaei et al. (2020) also highlighted AR's ability to facilitate reading comprehension by providing visual and auditory cues. They found that children who read an AR-enabled storybook scored better on retelling and recalling the story than those who read the same story in print format alone. The AR storybook supplemented the printed text with related multimedia content, such as videos and animations, on a tablet. This interactive augmented experience improved reading comprehension by enhancing engagement with the story and supporting understanding of complex concepts. The findings indicated that combining print books with digital enrichment through AR interfaces holds educational potential for developing early literacy skills (Danaei & et al., 2020). Some studies have explored the factors that influence the effectiveness of AR on reading comprehension, such as the type of AR device (Chen et al., 2020), the level of interactivity (Diegmann et al., 2015), the design of AR content (Ibáñez et al., 2014), and the learners' preferences and attitudes (Parmaxi & Demetriou, 2020). These studies suggest that AR can be useful for reading comprehension if implemented appropriately and aligned with the learners' needs and goals.

However, limitations were present in sample size and demographics in these studies. Furthermore, few studies have rigorously compared AR interventions to traditional reading instruction over an extended period. While initial evidence points to the promise of AR for reading comprehension, further research is needed to corroborate results for diverse learners' needs across proficiency levels in different contexts.

## Methodology

### Study design

The study employed a sequential explanatory mixed-methods design to answer the research questions. It consisted of a quantitative quasi-experimental phase followed by a qualitative phase to provide greater insight into the quantitative results (Creswell et al., 2003). This design allowed the researchers to assess the AR intervention's impact on reading comprehension using pre/posttests. Then, it explored teacher perspectives to help explain the quantitative findings and explore their experiences with AR technology in the classroom. The quantitative phase utilized a non-equivalent pretest-posttest control group design appropriate for educational research when random assignment is impossible (Dimitrov & Rumrill, 2003). This design enabled the researchers to measure and compare the student participants' learning outcomes before and after the AR intervention using statistical tests. The qualitative phase involved semi-structured interviews with teachers implementing the AR intervention in their language classes. The interviews were audio-

recorded, transcribed, and analyzed using thematic analysis, a rigorous and systematic method for identifying and interpreting patterns of meaning in qualitative data (Braun & Clarke, 2006). The interviews aimed to gain their perspectives on using AR technology in the classroom and its impact on their teaching practices and students' learning outcomes. Integrating both forms of data provided a comprehensive understanding of the AR intervention and its effects on reading comprehension and teacher experiences.

## Participants

The sample of this study consisted of 98 EFL participants who attended a language institute in Iran, specifically at Daneshpazhoohan Higher Education Institution in Isfahan. The participants were Persian native speakers aged between 22 and 36. To ensure a certain level of proficiency, the researchers administered the Oxford Quick Placement Test (OQPT) as a standardized and reliable measure of English language proficiency. Only participants who scored between 40 and 59 on the OQPT, corresponding to the B1 Common European Framework of Reference for Languages (CEFR) level, were included in the study. This proficiency range was necessary for the effective implementation of the AR-based learning activities. The participants were randomly assigned to either the experimental group (EG) or the control group (CG) to minimize selection bias. The teachers who were interviewed in this study were indeed the instructors of the control and experimental groups in this instructional experiment. They played a central role in delivering instruction and facilitating the AR-enhanced and traditional teaching methodologies. The inclusion of these teachers as interviewees allowed for a comprehensive understanding of the learners' motivation and engagement in AR-based learning. As instructors, they had direct interaction with the participants, monitored their progress, and were able to provide valuable insights into the learners' experiences, challenges, and level of engagement with the AR technology and instructional approaches. Their firsthand experiences and observations within the specific instructional context of the study enabled them to address the interview questions and provide valuable perspectives on the comparative effectiveness of AR-enhanced instruction and traditional teaching methods. It is important to note that the teachers who were interviewed met specific inclusion criteria, including a minimum of two years of teaching experience, a bachelor's degree or higher in English language teaching or a related field, and some familiarity with AR technology or a willingness to learn about it. This ensured that the interviewed teachers possessed the necessary qualifications and experience to provide informed insights on the learners' motivation and engagement in AR-based learning.

## Instruments

To ensure comparability and establish a baseline for reading comprehension proficiency, the researchers employed the validated Dialang assessment system (Alderson & Huhta, 2005) for both the pretest and posttest. The use of parallel forms of the Dialang reading test allowed for assessing learners' proficiency before and after the AR intervention while controlling for test familiarity effects. The Dialang reading test was chosen due to its rigorous development process and psychometric validation, aligning with the Common European Framework of Reference for Languages (CEFR) standards. This test includes authentic reading passages and multiple-choice questions that assess various skills such as main idea comprehension, detail extraction, vocabulary, and inference-making. It is important to note that the Dialang tests are online diagnostic tests designed to evaluate proficiency in multiple European languages, including English. These tests are specifically developed based on the CEFR levels and provide immediate feedback and advice to test-takers regarding their language strengths and weaknesses (Dialang, n.d.). The tests consist of three components: a self-assessment questionnaire, a placement test, and a diagnostic test. The self-assessment questionnaire prompts learners to self-rate their language skills according to the CEFR levels. The placement test comprises 15 multiple-choice questions aimed at determining the appropriate level for the diagnostic test. The diagnostic test consists of 30 multiple-choice questions that measure proficiency in a specific skill or aspect, such as reading comprehension, at a particular CEFR level (e.g., B1). Extensive research has demonstrated the high reliability and validity of the Dialang tests across various contexts (Alderson et al., 2006; Zhang & Thompson, 2004). In this study, the Dialang reading tests were administered online to the learners both before and after the intervention. These tests served to establish their general English level and reading proficiency baseline, as well as gather posttest scores. The scores obtained were recorded and analyzed using descriptive statistics to describe the learners' profiles and to assign them to either the experimental or control groups based on their scores. By utilizing the Dialang reading test as a reliable and valid instrument, the study ensured a consistent and comparable measurement of reading comprehension proficiency before and after the intervention.

The study also used an AR web-based application called "XR Plus," a web-based platform that allows users to create augmented reality experiences without coding to develop and provide AR-based audio-visual and text materials. This platform enables users to create augmented reality experiences for free and without coding in a few minutes. XR Plus can be downloaded and used freely to create AR-based audio-visual materials.

The app was strategically chosen for its numerous advantages in augmenting reading comprehension. This innovative app leveraged augmented reality technology to overlay engaging audio-visual materials directly onto printed texts. Advanced image tracking

seamlessly displayed interactive 3D objects and digital information as enriching overlays. The immersive AR features helped learners deeply visualize and grasp complex or abstract concepts from the texts. This multimodal experience boosted learner engagement, motivation, interest in reading and strengthened cognitive and metacognitive skills. The app provided robust interactive features to enrich contextual vocabulary development. With embedded AR capabilities, learners could access definitions, parts of speech, pronunciations, collocations, and examples by tapping highlighted words in the passages. This immersive vocabulary support allowed learners to build lexical knowledge while improving holistic reading comprehension actively. This intuitive app designed for accessibility, interactivity, and adaptability enabled learners to easily access AR experiences through QR codes on their mobile devices without installations or downloads. The app worked offline and flexibly across all smartphone platforms, optimizing convenience and flexibility for self-directed learning anytime, anywhere. The pedagogically designed AR reading materials included seven topical texts, each paired with a complementary video accessible through QR codes. These videos provided supplemental information and visuals to enrich the texts.

### AR-based reading materials

The researchers integrated AR into English reading classes over six weeks. They selected "Focus on Vocabulary" Book 1 as the main resource for the classes because it offered intermediate-level texts that aligned with the CEFR B1 proficiency level of the learners. The texts also covered engaging topics that sparked the learners' interest and curiosity, such as happiness, human thinking, design, attraction, isolation, heroism, and waste. These topics provided rich opportunities for AR illustrations involving complex or abstract concepts that could be visualized with 3D objects and digital overlays.

Leveraging XR Plus technology, the researchers developed engaging augmented reality materials that brought the printed texts to life with interactive 3D objects and digital overlays. These AR elements enabled deeper visualization of key concepts, helping learners comprehend complex ideas. By scanning QR codes with their mobile devices, learners could access these AR enhancements layered onto the reading passages through the user-friendly web app.

Additionally, the app provided educational videos to activate background knowledge about each passage topic. Learners scanned codes with their phone cameras to view these videos, then discussed them collaboratively in groups and presented summaries. This pedagogically designed sequence integrating pre-reading AR videos, vocabulary-building passages, and cognition-boosting AR materials created a multimedia learning experience focused on reading skills. The thoughtfully embedded AR components enriched comprehension strengthened critical thinking, sparked creativity, and increased motivation.

## Procedure

In the first session, participants took Dialang tests to assess their general English level and reading proficiency, excluding those below B1. They were then introduced to the XR Plus AR app for enhanced reading and vocabulary learning, with pre-uploaded materials (see Figures 1, 2, 3). Teachers integrated the AR app into lessons, guiding students on its use and accessing content via QR codes for a multi-sensory vocabulary learning experience. Students interacted with AR-enhanced vocabulary during reading sessions, unlocking content with QR codes (see Figure 4), and participated in group discussions to deepen understanding. Over 12 sessions, the impact of AR on engagement and learning was monitored, focusing on vocabulary activities and student interaction with the technology. Figure 5 presents a summary of the steps in the procedure for the experimental group.

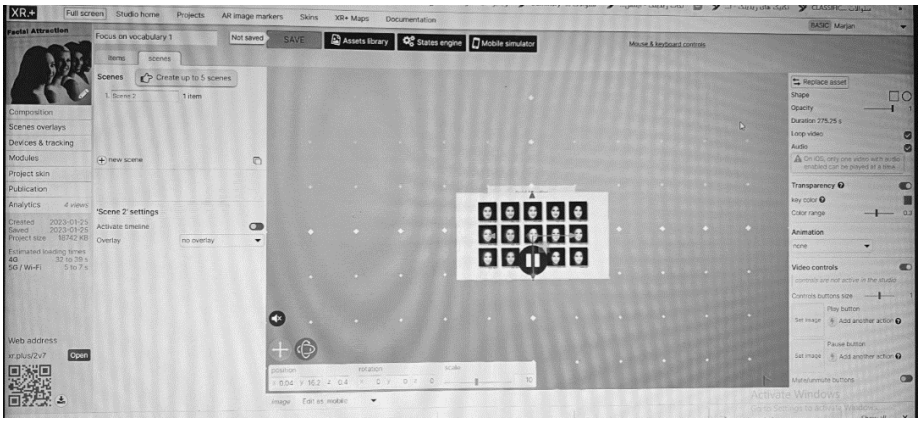


**Fig. 1** A screenshot of the educational video that relates to the reading passage topic

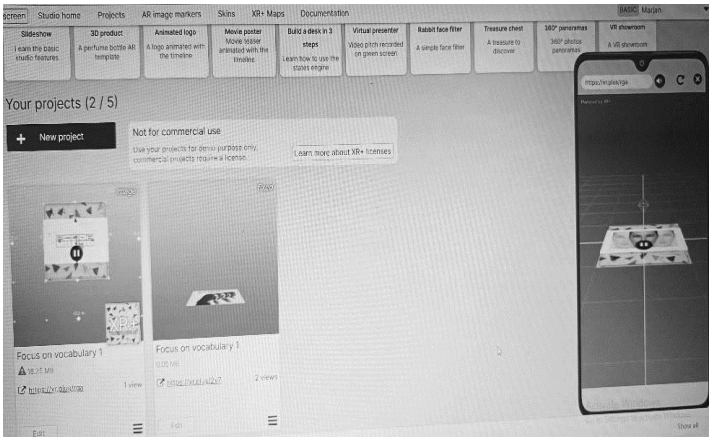


**Fig. 2** Selecting images and 3D objects for word meanings

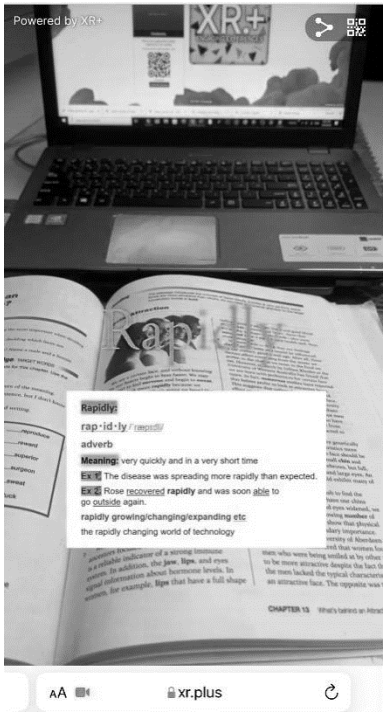


**Fig. 3** Providing word information, definitions, parts of speech, pronunciations, collocations, and examples

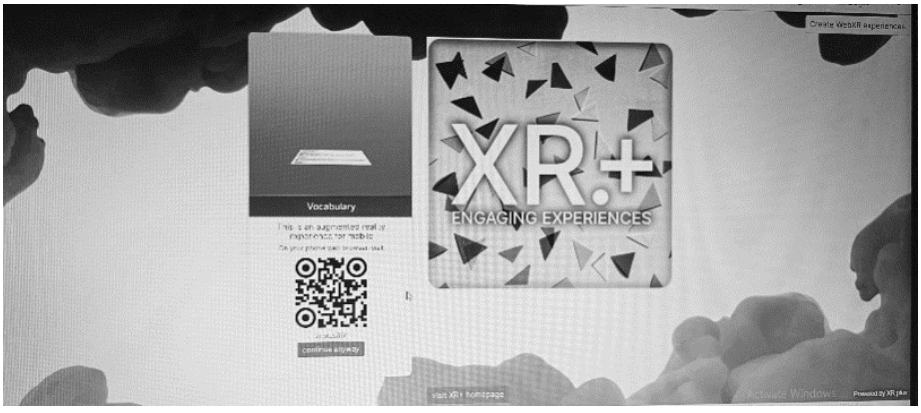


**Fig. 4** Custom QR codes and AR markers with footage sync

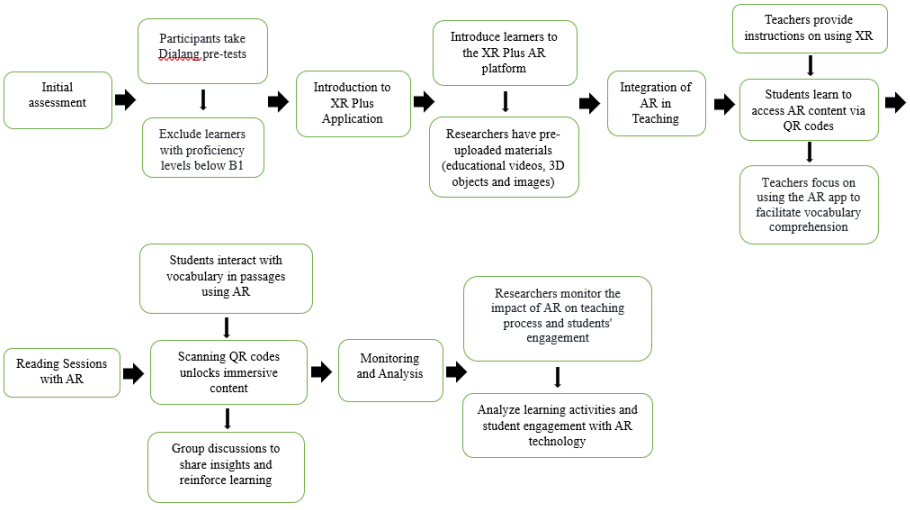


**Fig. 5** The schematic representation of procedure for the experimental group

Figure 5 presents the schematic representation of the study's procedure, detailing the steps specifically implemented for the experimental group. This includes the use of the XR Plus application and the AR-enhanced learning activities. On the other hand, the control group did not receive any AR-related interventions and followed the same procedures as the experimental group, except for the AR app introduction and activities.

The experiment lasted 12 sessions, with two 90-minute sessions per week in face-to-face classes. The focus of the study was on applying AR in English reading classes. For each session, the researcher chose one passage from "Focus on Vocabulary" (Book 1) with different topics, such as Why are you happy? When did humans begin to think? Easier on the eye-easier to use?, Facial attraction, Will they call us "generation isolation"?, Who's a hero? Waste-age. These topics were interesting and engaging for the learners. The vocabulary items were designed for intermediate students, and the difficulty level of all the readings corresponded to B1 in CEFR language proficiency levels. These units were specifically selected because they contained events and situations that could be illustrated and explained using AR.

The researcher used different educational videos related to the topic of each passage to activate the learners' background knowledge and prepare them for the reading. The learners were given a QR code and directed to the web-based XR Plus app to view the videos related to each topic and experience AR. After viewing the videos, they were put into small groups and asked to share their ideas. Finally, one presenter from each group reported the summary of their understanding. Therefore, it was expected to include the main idea, some

supporting details of the text, and some examples of the new vocabulary they learned from the AR materials.

Before the course, researchers provided learners with QR codes to access tailored AR materials prepared using the XR Plus platform. XR Plus delivered definitions, parts of speech, pronunciations, collocations, examples, and immersive AR experiences to aid comprehension of each passage's vocabulary item. Following a systematic development process, researchers identified challenging new words and consulted teachers to finalize selections. Next, they inputted explanatory textual components into XR Plus and chose relevant images and 3D objects to represent each word's meaning. The platform generated customized QR codes and AR markers. Researchers also curated educational videos to visualize concepts and boost understanding of passage topics by syncing related footage to QR codes. The AR materials underwent validation through piloting with similar learners. Researchers observed their interactions, gathered feedback through interviews, and refined the materials accordingly. This rigorous development and validation process ensured an optimal AR experience for the target learners.

The next phase was using AR materials to pre-teach the vocabulary items highlighted in the passages. Before the course started, the researcher provided QR codes to access AR materials he had prepared and uploaded on the XR Plus website. XR Plus provided necessary information such as definition, part of speech, pronunciation, collocations, and example sentences for all new vocabulary items in the passages and created an augmented reality experience for language learners, primarily visual learners. The learners used web-based apps on their smartphones, so when they pointed their phones at the highlighted words, they saw the information pop up (see Figures 6, 7).

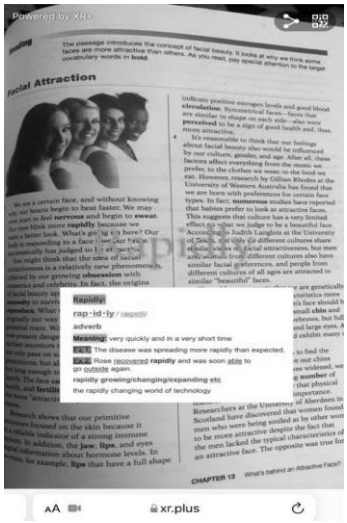


**Fig. 6** Scanning complex lesson vocabularies using XR app (sample 1)

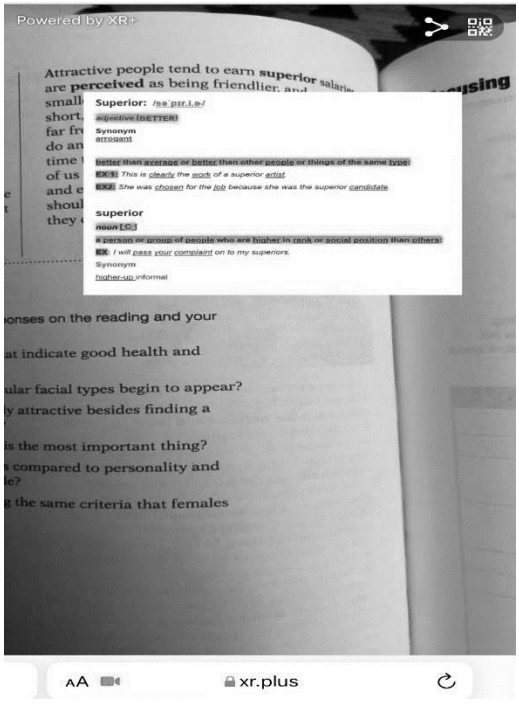


**Fig. 7** Scanning complex lesson vocabularies using XR app (sample 2)

An educational video was created and uploaded to the website for each topic. The learners could watch the video by pointing their mobile cameras at the topic. This was an effective way to engage the learners and make learning more interactive and fun (see Figures 8, 9).


**Fig. 8** Accessing lesson topic video through XR app (Sample 1)


**Fig. 9** Accessing lesson topic video through XR app (Sample 2)

The learners were presented with the definition, part of speech, pronunciation, collocations, and example sentences of the problematic and highlighted vocabulary items in the book through AR. The study used XR Plus to provide this information for the complex terms and create and display visual AR (video) teaching materials related to each passage and topic.

The book's author had already marked the challenging vocabulary items in the passages. The XR Plus app scanned these words and used them as AR image markers. The app showed the information and attached it to the scanned AR marker when the learners pointed their phones at the marked words to make learning more engaging and accessible (see Figure 10). The learners were allowed to use smartphones throughout the process.

The contents of the readings were analyzed to select suitable videos to make learning more interactive and fun for the learners. These videos were uploaded to the XR Plus website and linked to their AR image markers (the topics of the readings acted as the markers for the related videos). The learners used web-based apps on their smartphones, so when they pointed their phones at the topics and pictures, they saw the associated videos pop up (see Figures 11, 12).

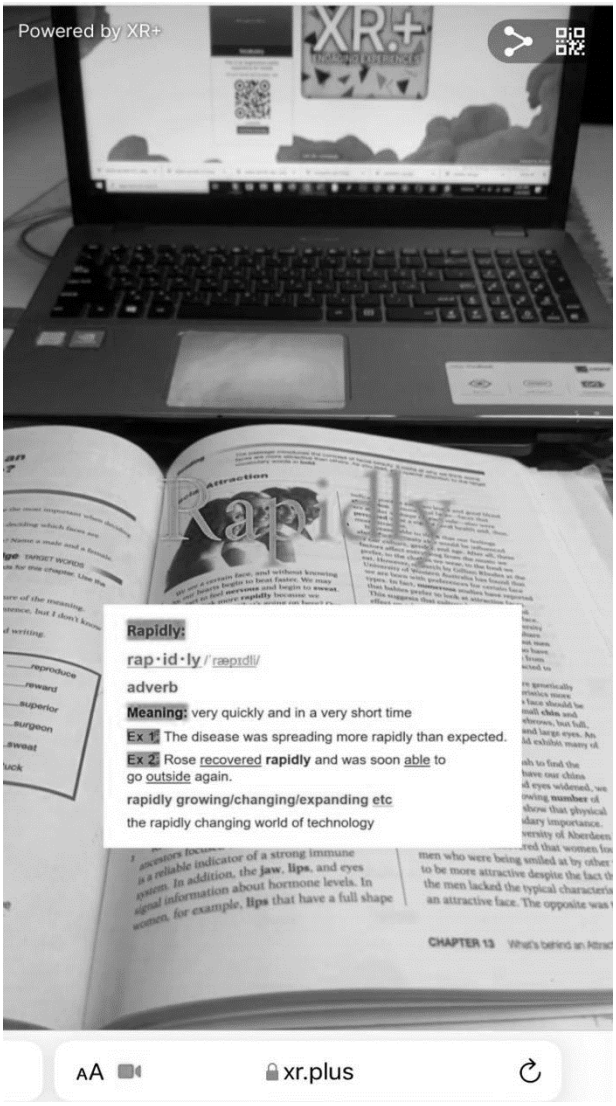


**Fig. 10** Scanning AR marker with XR app

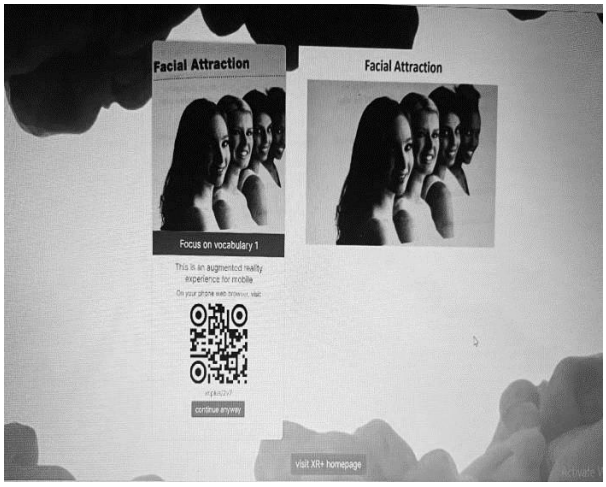


**Fig. 11** Custom QR code and AR marker

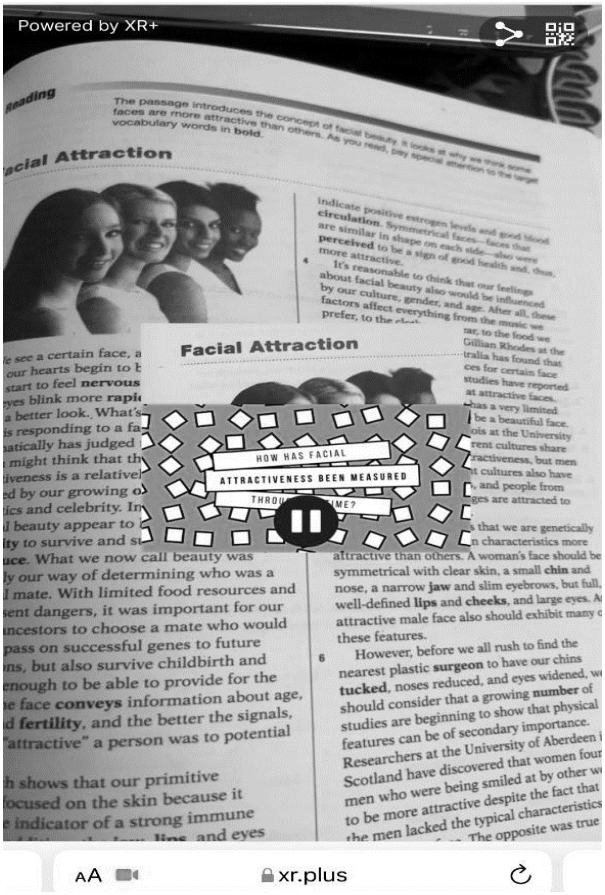


**Fig. 12** Accessing lesson topic video through XR app

At the end of each session, to reinforce learning and help learners apply what they learned in real-life situations, easy and motivational homework assignments were given to them that helped them relate what they learned to themselves.

## Control group activities

While the experimental group used augmented reality for reading comprehension, the control group relied on traditional paper materials. The control group received the same reading passages in a print format without AR elements.

To facilitate reading comprehension, the control group completed paper-based activities. In pre-reading, the instructor activated background knowledge through discussions and predictions. During reading, students did silent reading, read-aloud, scanning details, skimming main ideas, and close reading of challenging sections. For post-reading, students answered comprehension questions, created mind maps, and did roleplays and debates. For vocabulary building, the instructor pre-taught essential words using visuals. Students practiced form, meaning, and usage by matching words and definitions, filling in blanks, and word games. By engaging the control group in standardized reading and vocabulary activities using traditional materials, the study aimed to effectively develop their reading skills without AR.

The final session of the treatment involved a post-test that measured the learners' reading comprehension after the treatment. The post-test was similar to the pre-test in format, difficulty, and content. The posttest was administered to both groups (EG group and CG group) under the same conditions and time limit.

## Qualitative section

The interviews with the teachers aimed to elicit the teachers' views on the benefits and challenges of AR technology for EFL learners, as well as their own experiences and practices of using AR-based approaches in their classes. The interviews also sought to understand how AR influenced the learners' attitudes and achievement in reading comprehension tasks. This purpose was related to the research question of the effect of using AR on learning English among ESL learners, as it provided a qualitative perspective on the impact of AR from the teachers' standpoint. The interviews complemented the quantitative data from the tests by adding depth and context to the results.

The last session was allocated to interviewing. The teachers were informed about the study's purpose and procedures and their rights and responsibilities as participants. The teachers were experienced EFL teachers who had worked in the institute for over two years. Two had a bachelor's degree, and four had a master's in teaching English.

The interviews were conducted using a semi-structured interview protocol, which consisted of 8 open-ended questions that aimed to elicit the teachers' perceptions and

digital competencies regarding the use of AR in English reading comprehension. The questions were based on the literature review and the study's research objectives. The researchers conducted the interviews in a quiet and comfortable room at the language institute. The interviews were conducted in English, the common language between the researchers and the teachers. The interviews lasted about 30 minutes each and were recorded with the consent of the participants. The recorded interviews were transcribed verbatim by the researchers. The transcripts were analyzed using thematic analysis, which involved identifying, coding, and reporting themes and patterns within the data. The software NVivo was used to assist with the data analysis process. Member Checking (Cheng & Dörnyei, 2007) was employed to assess the credibility of the interview results.

### Thematic analysis procedure

Using a six-phase thematic analysis approach, as Braun and Clarke (2006) described, the study examined teacher interview transcripts. Reading through the transcripts in the first stage helped identify potential patterns, and labeling relevant elements in the second stage generated codes. The third phase centered on finding underlying themes by classifying codes and compiling samples. Potential themes were defined and named in the fourth phase, and the fifth phase, final themes were identified and analyzed. The sixth and final phase involved selecting and compiling extract examples and conducting a written analysis to ensure a logical, coherent, and internally consistent data account. This rigorous process yielded rich, detailed findings with optimal validity and reliability.

### Data analysis

The researchers used the Statistical Package for the Social Sciences (SPSS) version 26 to analyze the quantitative data. A One-way ANCOVA was conducted to examine the effect of AR applications on learners' reading comprehension. An independent-samples t-test was conducted to compare the EG and CG participants' reading comprehension after the treatment. The researchers also used qualitative thematic analysis to analyze the data from the interview. The analysis involved four steps. First, the researchers transcribed the audio recordings of the interview. Second, the researchers identified interesting features from the transcription and coded them accordingly. Third, the researchers categorized the codes into themes and reviewed and refined them to eliminate or merge redundant or overlapping themes. Fourth, the researchers reported the themes from the interview related to the three subscales of the IMI scale. Any other themes were discussed separately.

The Skewness and Kurtosis ratios were used to check the normality of the distribution of the variable of interest to ensure the suitability of parametric tests. The results confirmed that the variable was normally distributed. Therefore, the parametric test of ANCOVA was employed to address the first research question.

## Results

The researchers used SPSS 26.0 to analyze the quantitative data and answer the first research question. Table 1 shows the descriptive statistics and results of the normality test for the pretest and posttest scores of the two groups.

As indicated in the above table, the Skewness and Kurtosis ratios were all within the range of +/-1.96 and thus the normality assumption was warranted. Table 2 displays the results of the homogeneity of regression slopes.

As presented in Table 2, the significance value corresponding to Groups * Preboth equals .86 which is greater than 0.05, indicating that the assumption of the homogeneity of regression slopes was met. Table 3 displays the results of ANCOVA.

**Table 1** Results of descriptive statistics and normality test

| Groups | N | Mean | SD | Skewness | Std. Er | Kurtosis | Std. Er |
|---|---|---|---|---|---|---|---|
| Control Pretest | 34 | 12.39 | 2.27 | -.065 | .403 | -.938 | .788 |
| Control Posttest | 34 | 12.43 | 2.65 | -.214 | .403 | -.925 | .788 |
| Experimental Posttest | 34 | 15.61 | 3.16 | -.116 | .403 | -.974 | .788 |
| Experimental Pretest | 34 | 12.43 | 2.38 | .014 | .403 | -.962 | .788 |

**Table 2** Tests of between-subjects effects

| Dependent Variable: | Post Both | | | | | |
|---|---|---|---|---|---|---|
| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
| Corrected Model | 547.202[a] | 3 | 182.401 | 1000.684 | .000 | .979 |
| Intercept | 8.662 | 1 | 8.662 | 47.521 | .000 | .426 |
| Groups | 4.482 | 1 | 4.482 | 24.591 | .000 | .278 |
| Preboth | 372.368 | 1 | 372.368 | 2042.880 | .000 | .970 |
| Groups * Preboth | .005 | 1 | .005 | .029 | .866 | .000 |
| Error | 11.666 | 64 | .182 | | | |
| Total | 13971.000 | 68 | | | | |
| Corrected Total | 558.868 | 67 | | | | |

a. R Squared = .979 (Adjusted R Squared = .978)

**Table 3** Results of ANCOVA

| Dependent Variable: | Post Both | | | | | |
|---|---|---|---|---|---|---|
| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
| Corrected Model | 547.197[a] | 2 | 273.598 | 1523.784 | .000 | .979 |
| Intercept | 8.689 | 1 | 8.689 | 48.395 | .000 | .427 |
| Preboth | 372.476 | 1 | 372.476 | 2074.476 | .000 | .970 |
| Groups | 133.114 | 1 | 133.114 | 741.369 | .000 | .919 |
| Error | 11.671 | 65 | .180 | | | |
| Total | 13971.000 | 68 | | | | |
| Corrected Total | 558.868 | 67 | | | | |

a. R Squared = .979 (Adjusted R Squared = .978)

As seen in Table 3, the significance value corresponding to the groups turned out to be smaller than the critical value ($p$= .00<.001), indicating that there was a significant difference between the performances of the two groups in terms of reading comprehension scores. The partial eta squared turned out to be .91, which is an indication of a large effect size (Cohen, 1988). Table 4 demonstrates the estimated marginal means for the control and experimental groups' scores.

Table 4 presents the pairwise comparison between the control and experimental groups' reading compression scores.

As indicated in Table 5, the significance value equals .00 which is lower than 0.001. Moreover, as shown in Table 4, the estimated marginal means for the control and experimental groups were 12.64 and 15.44, respectively. Thus, it can be inferred that the experimental group significantly outperformed the control group in terms of reading comprehension scores. Therefore, it can be concluded that using AR significantly affected reading progress. Thus, the research hypothesis with 95% confidence is accepted.

The researchers also collected qualitative data from a semi-structured interview to answer the second question. The interview explored the teachers' perceptions of AR and its benefits and challenges for teaching English. The analysis revealed that teachers had positive attitudes toward using AR in language learning. The teachers valued AR technology as an effective and beneficial tool for EFL learners. They recognized its potential for facilitating deep learning of language skills, enhancing learners' motivation

**Table 4** Estimated marginal means

| Dependent Variable: Post Both | | | | |
|---|---|---|---|---|
| | | | 95% Confidence Interval | |
| Groups | Mean | Std. Error | Lower Bound | Upper Bound |
| Control | 12.640[a] | .073 | 12.495 | 12.785 |
| Experimental | 15.448[a] | .073 | 15.303 | 15.594 |

a. Covariates appearing in the model are evaluated at the following values: Pre Both = 12.5882

**Table 5** Pairwise comparison between the control and experimental groups

| Dependent Variable: Post Both | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | 95% Confidence Interval for Difference[b] | |
| (I) Groups | (J) Groups | Mean Difference (I-J) | Std. Error | Sig.[b] | Lower Bound | Upper Bound |
| Control | Experimental | -2.808* | .103 | .000 | -3.014 | -2.602 |

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

and engagement, and increasing their willingness to use AR-based approaches in EFL classes. They also reported some challenges and limitations of using AR, such as technical issues, cost, accessibility, usability, ethical concerns, etc.

Teachers reported that AR facilitated students' reading comprehension by providing interactive and multimodal information that supported their understanding of the text and vocabulary. They also observed that students enjoyed using AR and found it fun and exciting to learn with AR. Teachers explained that they prepared the students for using AR by showing them videos related to each topic and providing them with adequate background knowledge. They also noted that AR offered rich and contextualized information about new vocabulary, such as definitions, synonyms, examples, and sentence usage, which helped the students learn and retain the vocabulary better. Teachers stated that these features of AR were aligned with the motivational theory and the constructivist learning theory, which suggest that learners are motivated and construct knowledge when they are actively engaged with their environment and interact with various sources of information.

## Qualitative analysis of the interviews

This qualitative section investigates educators' perceptions and experiences with Augmented Reality (AR) as an innovative language-learning support. The following overarching themes emerge from a thematic analysis of interview excerpts.

### AR as an engaging and motivating tool for language learning

Educators consistently reported that AR technology significantly enhanced student engagement and motivation in language learning. Teachers observed that the use of AR made lessons more dynamic and captivating, increasing students' participation and interest. One teacher noted, "The students were very interested and motivated to use AR" (Participant 15). Another mentioned, "The students were excited and engaged when we used AR for our reading lessons" (Participant 4). The interactive nature of AR transformed the learning environment, making it more enjoyable and fun, as one teacher highlighted, "You could see their motivation and enjoyment as they interacted with the technology" (Participant 11).

### AR as a facilitator of reading comprehension

AR's interactive and multimodal nature played a significant role in improving students' reading comprehension. Educators found that AR helped students better understand and engage with the text by providing additional context through 3D models, videos, and other multimedia elements. "AR helped them understand the text better by providing different information types," noted one teacher (Participant 19). Another teacher observed, "AR

facilitated the students' understanding of the texts" (Participant 7). The supportive elements of AR were crucial in enhancing comprehension, with one educator commenting, "The interactive 3D models and videos supported their comprehension and gave them additional context" (Participant 3).

### AR as a facilitator of instruction and teaching process

Teachers found AR to be an invaluable tool for delivering personalized and interactive instruction. The technology enabled them to differentiate instruction and meet diverse student needs effectively. "AR facilitated instruction by providing interactive and differentiated learning experiences," noted one educator (Participant 2). Another teacher highlighted how AR allowed for more tailored teaching approaches: "AR technology allowed for personalized instruction catering to the diverse needs of students" (Participant 18). This adaptability was seen as a major advantage of integrating AR into the teaching process.

### Learning outcomes in reading comprehension

The impact of AR on students' reading comprehension skills was significant, according to the educators. Students showed marked improvements in comprehension strategies and their ability to analyze and infer from texts after engaging with AR. One teacher stated, "AR significantly improved students' reading comprehension skills as evidenced by their ability to analyze texts and make accurate inferences" (Participant 5). Another added, "Students demonstrated a deeper understanding of the texts after engaging with AR-based learning activities" (Participant 21). These outcomes underscore the effectiveness of AR in enhancing students' reading comprehension.

### Learning outcomes in vocabulary learning

AR technology also contributed to substantial improvements in vocabulary acquisition and retention. Educators observed that students' word knowledge expanded significantly, and they were better able to use new vocabulary effectively. "AR contributed to substantial growth in students' vocabulary learning resulting in expanded word knowledge and improved retention," noted one teacher (Participant 10). Another highlighted the practical application of new words: "The use of AR technology enabled students to apply newly learned vocabulary in meaningful contexts" (Participant 1). These observations point to the effectiveness of AR in vocabulary learning.

### Learning outcomes in understanding complex concepts

AR facilitated the understanding of complex and abstract concepts by providing visual and interactive representations. Teachers noted that this approach helped students grasp

challenging topics more effectively. “AR facilitated students’ understanding of complex concepts by providing visual and interactive representations,” explained one educator (Participant 16). Another observed, “Students demonstrated a higher level of cognitive development and a deeper conceptual understanding of challenging topics through AR-enhanced learning experiences” (Participant 9). These insights highlight the cognitive benefits of using AR in education.

### AR as a vocabulary learning aid

Teachers appreciated the specific aids AR provided for vocabulary learning, such as definitions, synonyms, examples, and usage contexts. This comprehensive approach supported students’ vocabulary acquisition. “AR gave them more information about the new words such as their meanings, synonyms, examples, and how to use them in sentences,” noted one teacher (Participant 8). Another emphasized the convenience and effectiveness of AR, stating, “With AR, the students could access definitions, pronunciations, and examples for new vocab words all in one place. This really aided their vocabulary learning process” (Participant 13).

### Preparation for using AR

Preparation was key to maximizing the effectiveness of AR in the classroom. Teachers found that providing background knowledge through videos and discussions before using AR improved student engagement and understanding. “We showed them some videos related to the topic before using AR to give them some background knowledge,” explained one educator (Participant 6). Another added, “Before starting any AR activities, I would prep students by showing topical videos and holding discussions to build background knowledge” (Participant 12). These preparatory steps were seen as essential for successful AR implementation.

### Challenges and limitations of using AR

Educators encountered various challenges and limitations when using AR in the classroom, including technical issues, high costs, accessibility problems, and ethical concerns regarding privacy and security. “We faced some challenges in using AR such as the unstable internet connection, the devices being expensive and not easy to use, and some ethical concerns about privacy and security,” noted one teacher (Participant 22). Another reported, “We encountered technical problems quite frequently. The devices and software also had limitations in terms of accessibility and usability” (Participant 14). These challenges highlighted the need for careful consideration and planning when integrating AR into educational settings.

### Solutions and recommendations for using AR

To address the challenges and enhance the effectiveness of AR in classrooms, educators suggested several solutions and recommendations. These included having backup plans, providing more training, and offering better guidance for both students and teachers. "We suggested some solutions for using AR better such as having a backup plan in case of technical problems and providing more training and guidance for the students and teachers on how to use AR effectively and safely," stated one teacher (Participant 17). Another emphasized the importance of preparation: "Strong backup lesson plans are crucial if you run into AR issues. More training on troubleshooting problems would help us use the technology more smoothly" (Participant 20). These recommendations aimed to improve the integration and utilization of AR in educational contexts.

The findings generally provide valuable insights into the experiences of educators using augmented reality as a tool for language learning. They demonstrate that augmented reality has the potential to increase engagement, facilitate comprehension, and facilitate vocabulary acquisition. However, the study identifies relevant obstacles and provides actionable suggestions for enhancing augmented reality integration in educational settings. To completely utilize the benefits of AR in language-learning pedagogy, additional research and collaborative efforts are required.

The findings reveal that AR technology facilitates instruction by providing interactive and differentiated learning experiences, allowing for personalized instruction and catering to the diverse needs of students. Moreover, it significantly improves students' reading comprehension skills, as they demonstrate the ability to analyze texts, make accurate inferences, and develop effective comprehension strategies. Students also experience substantial growth in vocabulary learning, expanding their word knowledge and demonstrating improved retention and application of newly learned words in meaningful contexts. Additionally, AR enhances students' understanding of complex concepts by providing visual and interactive representations, leading to higher levels of cognitive development and a deeper conceptual understanding of challenging topics.

## Discussion

The results prove that AR-enhanced instruction significantly improved the reading comprehension scores of the experimental group. These findings suggest that AR improved students' reading comprehension and vocabulary learning. These results confirm previous research showing that AR can improve reading outcomes (Chen & Tsai, 2012; Liu & Tsai, 2013). These results are consistent with previous studies that AR can enhance reading comprehension and vocabulary learning by providing interactive and multimodal information that supports learners' understanding (e.g., Chen & Tsai, 2012; Liu & Tsai, 2013). This result also corresponds to the positive perceptions of the teachers resulting

from the thematic analysis of the interviews. Teachers emphasized AR's ability to motivate and engage students, as evidenced by one teacher's statement: "Students were very interested and motivated to use AR." This increased engagement likely contributed to and supported deeper processing of the reading material observed gains in understanding. Additionally, teachers reported that AR's interactive features, such as 3D models and videos, facilitated understanding by providing multimodal information. This is consistent with constructivist learning theory, where students actively construct knowledge through interaction with various sources (Jonassen & Rohrer-Murphy, 1999). Integrating text, images, audio, and video into the AR app conforms to this principle and potentially results in richer learning experiences compared to previous studies that only used text and images.

However, the novel AR intervention differs from those used in previous research, highlighting the need for studies on effective AR reading design features (Dunleavy, 2014; Ysseldyke & Bolt, 2007). Additionally, the alignment with constructivist theory (Duffy & Cunningham, 1996; Jonassen & Rohrer-Murphy, 1999) offers a framework to understand AR's benefits, unlike some prior studies that lacked a theoretical basis (Cheng & Tsai, 2012). By demonstrating AR's positive impact using a rigorous experimental design, novel AR intervention, and theoretical framework, the current study offers valuable and unique contributions compared to previous research. The study extends previous findings by providing strong evidence of AR's potential to improve reading while highlighting the need for theoretically grounded and deliberately designed AR interventions to maximize impact.

The second research question explored the teachers' perceptions of AR and its benefits and challenges for teaching English. The semi-structured interview results revealed that the teachers had positive attitudes toward using AR in language learning. They valued AR technology as an effective and beneficial tool for EFL learners. They recognized its potential for facilitating deep learning of language skills, enhancing learners' motivation and engagement, and increasing their willingness to use AR-based approaches in EFL classes. Furthermore, the results showed that AR technology facilitates instruction by providing interactive and differentiated learning experiences, allowing for personalized instruction and catering to the diverse needs of students.

While the current study highlights AR's potential, thematic analysis also revealed challenges teachers encountered with AR. These included technical issues (e.g., unstable internet connection) and accessibility concerns (e.g., device cost), as exemplified by one teacher's statement: "We faced some challenges in applying the AR app, as the devices are expensive and not easy to use." Providing teachers with proper training on troubleshooting common AR issues would be extremely beneficial. Additionally, training students on using the AR app effectively would likely minimize initial confusion and maximize their learning experience. The study demonstrated that AR can significantly improve EFL learning, but challenges remain in integrating it effectively. Future research should explore features,

professional development, and best practices to maximize AR's potential for language learning. The findings of this study corroborate those of Danaei et al., (2020) finding that AR can enhance reading comprehension by providing visual and auditory cues that facilitate engagement and retention. In contrast, our findings contradict Parmaxi and Demetriou (2020), who concluded that augmented reality had no significant impact on vocabulary learning and reading comprehension when compared to conventional approaches. They attributed this to the low level of interactivity and personalization of the AR content, as well as the technical difficulties and distractions that the learners faced. This suggests that the effectiveness of AR may depend on various factors, such as the design of the AR content, the type of the AR device, and the learners' preferences and attitudes. Unlike Shaaban and Mohamed (2024) and Ebadi and Ashrafabadi (2022), this study used a larger sample size (N = 98) and a control group. This provided more robust evidence of AR's effectiveness. Additionally, The AR app used in this study integrated text, images, audio, video, and animations, while the previous studies used AR-based mobile applications that only provided text and images.

Regarding pedagogical implications, the study suggests that teachers and students should evaluate the benefits and challenges of using augmented reality (AR) technology for EFL learning. They should select the appropriate technology, provide comprehensive training, design engaging learning activities, and monitor progress. Students should use AR responsibly and independently, seeking help when needed.

This study explored the effectiveness of an AR application, XR Plus in enhancing EFL learners' reading comprehension skills. The app was chosen for its ability to integrate various multimedia elements, including text, images, audio, video and animations, providing a richer and more interactive learning experience compared to previous studies that primarily utilized mobile AR applications that only offered text and images.

Building on previous research that demonstrated AR's promise in reading comprehension, this study highlights the importance of well-designed AR interventions incorporating rich multimedia elements. Future research should explore AR's impact on a broader range of language skills, including listening, speaking, and writing. Additionally, factors that influence the effectiveness of AR in EFL educational contexts should be considered. These factors may include the design of the AR materials (including multimedia elements), the type of AR device used (e.g., smartphones vs. head-mounted displays), and learners' preferences and learning styles.

We acknowledge the limitation of the six-week duration for assessing the long-term impact of augmented reality (AR) technology on English as a Foreign Language (EFL) learning. However, this study successfully evaluated the initial effects of AR on reading comprehension and underscored the importance of well-designed AR interventions. The six-week period proved sufficient to determine the feasibility of implementing AR in an

EFL environment, identify challenges, refine methodologies, and gather baseline data for longer-term studies (Imtiaz et al., 2017). The specific timeframe allowed us to concentrate on the impact of multimedia elements effectively. Short-term studies, like the present one, are instrumental in measuring immediate impacts on student engagement, motivation, and learning outcomes, which are crucial for the long-term adoption of AR technologies (Lee & Park, 2020). Additionally, we propose further investigations into different forms and devices of AR technology in future studies to enhance the breadth of understanding in this domain. Longitudinal studies with extended durations could provide valuable insights into these aspects. Furthermore, the study primarily utilized web-based AR accessed via smartphones. Future research comparing different forms and devices of AR technology could lead to a more comprehensive understanding of the potential of AR for EFL learning experiences. The study also suggests further research to identify necessary technological instruments and investigate students' perceptions and attitudes towards AR technology. In-depth interviews with students and educators can provide valuable insights. The findings contribute to the growing body of knowledge on AR in EFL learning. It demonstrates AR's potential to improve reading comprehension while highlighting the importance of well-designed interventions and the need for further research to optimize its effectiveness in EFL contexts.

## Appendix

| Interview Questions | |
|---|---|
| 1. | In what ways have you seen AR technology engage and motivate students during reading comprehension activities? Can you provide any examples? |
| 2. | How has using AR helped facilitate your students' reading comprehension? What evidence have you seen of this? |
| 3. | How has AR supported your students' vocabulary learning during reading lessons? Can you give examples? |
| 4. | How do you effectively prepare and support students in using AR technology for reading comprehension? |
| 5. | In your view, how is AR aligned with language learning theories like constructivism and motivation? Why? |
| 6. | What changes in student motivation, engagement, or reading skills have you noticed when using AR versus traditional methods? |
| 7. | What challenges or limitations have you experienced when implementing AR for reading lessons? How have you addressed them? |
| 8. | What training or professional development related to AR integration has helped build your digital competencies? What additional support would further develop your skills? |

**Abbreviations**

AR: Augmented Reality; OQPT: Oxford Quick Placement Test; CEFR: Common European Framework of Reference for Languages; EG: Experimental Group; CG: Control Group; EFL: English as a Foreign Language.

**Authors' contributions**

MA conducted the course, collected the data, performed data analysis and drafted the first manuscript.

SE provided insight, reviewed the final draft, and made necessary revisions.

Both authors read and approved the final manuscript.

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**Competing interests**

The authors declare that they have no competing interests.

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**References**

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review*, *20*(1), 1–11. https://doi.org/10.1016/j.edurev.2016.11.002

Alderson, J. C., & Huhta, A. (2005). The development of a suite of computer-based diagnostic tests based on the Common European Framework. *Language Testing*, *22*(3), 301–320. https://doi.org/10.1191/0265532205lt310oa

Alderson, J. C., Figueras, N., Kuijper, H., Nold, G., Takala, S., & Tardieu, C. (2006). Analyzing tests of reading and listening in relation to the Common European Framework of Reference: The experience of The Dutch CEFR construct project. *Language Assessment Quarterly*, *3*(1), 3–30. https://doi.org/10.1207/s15434311laq0301_2

Alkhabra, Y. A., Ibrahem, U. M., & Alkhabra, S. A. (2023). Augmented reality technology in enhancing learning retention and critical thinking according to STEAM program. *Humanities and Social Sciences Communications*, *10*, 174. https://doi.org/10.1057/s41599-023-01650-w

Belda-Medina, J., & Marrahi-Gomez, V. (2023). The impact of Augmented Reality (AR) on vocabulary acquisition and student motivation. *Electronics*, *12*(3), 749. https://doi.org/10.3390/electronics12030749

Billinghurst, M., & Duenser, A. (2012). Augmented Reality in the classroom. *Computer*, *45*(7), 56–63. https://doi.org/10.1109/MC.2012.111

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Chang, H.-Y., Binali, T., Liang, J.-C., Chiou, G.-L., Cheng, K.-H., Lee, S. W.-Y., & Tsai, C.-C. (2022). Ten years of augmented reality in education: A meta-analysis of (quasi-) experimental studies to investigate the impact. *Computers & Education*, *191*, 104641. https://doi.org/10.1016/j.compedu.2022.104641

Chen, C.-M., & Tsai, Y.-N. (2012). Interactive augmented reality system for enhancing library instruction in elementary schools. *Computers & Education*, *59*(2), 638–652. https://doi.org/10.1016/j.compedu.2012.03.001

Chen, J. C., Huang, Y., Lin, K. Y., Chang, Y. S., Lin, H. C., Lin, C. Y., & Hsiao, H. S. (2020). Developing a hands-on activity using virtual reality to help students learn by doing. *Journal of Computer Assisted Learning*, *36*(1), 46–60. https://doi.org/10.1111/jcal.12389

Chen, P., Liu, X., Cheng, W., & Huang, R. (2016). A review of using Augmented Reality in Education from 2011 to 2016. In E. Popescu et al. (Eds.), *Innovations in smart learning* (pp. 13–18). Springer, Singapore. https://doi.org/10.1007/978-981-10-2419-1_2

Cheng, H.-F., & Dörnyei, Z. (2007). The use of motivational strategies in language instruction: The case of EFL teaching in Taiwan. *Innovation in Language Learning and Teaching*, *1*(1), 153–174. https://doi.org/10.2167/illt048.0

Cheng, K.-H., & Tsai, C.-C. (2012). Affordances of augmented reality in science learning: Suggestions for future research. *Journal of Science Education and Technology*, *22*(4), 449–462. https://doi.org/10.1007/s10956-012-9405-9

Creswell, J. W., Plano Clark, V. L., Gutmann, M. L., & Hanson, W. E. (2003). Advanced mixed methods research designs. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of mixed methods in social and behavioral research* (pp. 209–240). Sage.

Danaei, D., Jamali, H. R., Mansourian, Y., & Rastegarpour, H. (2020). Comparing reading comprehension between children reading augmented reality and print storybooks. *Computers & Education*, *153*, 103900. https://doi.org/10.1016/j.compedu.2020.103900

Diegmann, P., Schmidt-Kraepelin, M., Eynden, S., & Basten, D. (2015). Benefits of Augmented Reality in educational environments - A systematic literature review. In O. Thomas & F. Teuteberg (Eds.), *Wirtschaftsinformatik Proceedings 2015* (pp. 1542–1556). Association for Information Systems. https://aisel.aisnet.org/wi2015/103/

Dimitrov, D. M., & Rumrill, J. (2003). Pretest-posttest designs and measurement of change. *Work*, *20*(2), 159–165. https://content.iospress.com/articles/work/wor00285

Duffy, T. M., & Cunningham, D. J. (1996). Constructivism: Implications for the design and delivery of instruction. In D. H. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 170–198). Simon & Shuster Macmillan. https://cir.nii.ac.jp/crid/1573950399758701312

Dunleavy, M. (2014). Design principles for augmented reality learning. *TechTrends*, *58*(1), 28–34. https://doi.org/10.1007/s11528-013-0717-2

Ebadi, S., & Ashrafabadi, F. (2022). An exploration into the impact of augmented reality on EFL learners' Reading comprehension. *Education and Information Technologies*, *27*(7), 9745–9765. https://doi.org/10.1007/s10639-022-11021-8

Grabe, W. (2009). Teaching and testing reading. In M. H. Long & C. J. Doughty (Eds.), *The handbook of language teaching* (pp. 441–462). Blackwell Publishing Ltd. https://doi.org/10.1002/9781444315783.ch24

Huisinga, L. A. (2017). *Augmented reality reading support in higher education: Exploring effects on perceived motivation and confidence in comprehension for struggling readers in higher education*. Doctoral dissertation, Iowa State University.

Ibáñez, M. B., Di Serio, Á., Villarán, D., & Delgado Kloos, C. (2014). Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness. *Computers & Education*, *71*, 1–13. https://doi.org/10.1016/j.compedu.2013.09.004

Imtiaz, H., Fatimah, A., Aslam, S., & Waqar, A. (2017). Effect of technology enhanced language learning on EFL reading comprehension at tertiary level. *Arab World English Journal*, *8*, 108–129. https://doi.org/10.24093/awej/vol8no1.9

Jafarigohar, M., & Behrooznia, S. (2012). The effect of anxiety on reading comprehension among distance EFL learners. *International Education Studies*, *5*(2), 159–174. https://doi.org/10.5539/ies.v5n2p159

Jonassen, D. H., & Rohrer-Murphy, L. (1999). Activity theory as a framework for designing constructivist learning environments. *Educational Technology Research and Development*, *47*(1), 61–79. https://doi.org/10.1007/bf02299477

Khataee, E. (2018). Reading failure among Iranian EFL learners: Study of underlying problems. *Journal of English Language & Translation Studies*, *6*(3), 164–176.

Lee, S., & Park, M. (2020). Reconceptualization of the context in language learning with a location-based AR app. *Computer Assisted Language Learning*, *33*, 936–959. https://doi.org/10.1080/09588221.2019.1602545

Liu, P. H. E., & Tsai, M. K. (2013). Using augmented-reality-based mobile learning material in EFL English composition: An exploratory case study. *British Journal of Educational Technology*, *44*(1), E1–E4. https://doi.org/10.1111/j.1467-8535.2012.01302.x

Morrow, D. G., Bower, G. H., & Greenspan, S. L. (1989). Updating situation models during narrative comprehension. *Journal of Memory and Language*, *28*(3), 292–312. https://doi.org/10.1016/0749-596x(89)90035-1

Mozaffari, S., & Hamidi, H. R. (2023). Impacts of augmented reality on foreign language teaching: A case study of Persian language. *Multimedia Tools and Applications*, *82*(3), 4735–4748. https://doi.org/10.1007/s11042-022-13370-5

Mystakidis, S., Fragkaki, M., & Filippousis, G. (2021). Ready teacher one: Virtual and augmented reality online professional development for K-12 school teachers. *Computers*, *10*(10), 134. https://doi.org/10.3390/computers10100134

Ou Yang, F.-C., Lai, H.-M., & Wang, Y.-W. (2023). Effect of augmented reality-based virtual educational robotics on programming students' enjoyment of learning, computational thinking skills, and academic achievement. *Computers & Education*, *195*(C), 104721. https://doi.org/10.1016/j.compedu.2022.104721

Palani, K. K. (2021). Promoting reading habits and creating literate society. *Researchers World - International Refereed Social Sciences Journal*, *3*(2(1)), 90–94. https://www.researchersworld.com/index.php/rworld/article/view/591

Parmaxi, A., & Demetriou, A. A. (2020). Augmented reality in language learning: A state-of-the-art review of 2014–2019. *Journal of Computer Assisted Learning*, *36*(6), 861–875. https://doi.org/10.1111/jcal.12486

Perfetti, C., & Stafura, J. (2014). Word knowledge in a theory of reading comprehension. *Scientific Studies of Reading*, *18*(1), 22–37. https://doi.org/10.1080/10888438.2013.827687

Piaget, J. (1970). Piaget's theory. In P. Mussen (Ed.), *Carmichael's manual of child psychology, Vol. 1* (pp. 703–832). Wiley.

Piriyasurawong, P. (2020). Scaffolding Augmented Reality Model to Enhance Deep Reading Skill. *TEM Journal*, *9*(4), 1760–1764. https://doi.org/10.18421/TEM94-58

Radu, I., Huang, X., Kestin, G., & Schneider, B. (2023). How augmented reality influences student learning and inquiry styles: A study of 1-1 physics remote AR tutoring. *Computers & Education: X Reality*, *2*, 100011. https://doi.org/10.1016/j.cexr.2023.100011

Radvansky, G. A. (1999). The fan effect: A tale of two theories. *Journal of Experimental Psychology: General*, *128*(2), 198–206. https://doi.org/10.1037/0096-3445.128.2.198

Sat, M., Ilhan, F., & Yukselturk, E. (2023). Comparison and evaluation of augmented reality technologies for designing interactive materials. *Education and Information Technologies*, *28*, 11545–11567. https://doi.org/10.1007/s10639-023-11646-3

Shaaban, T. S., & Mohamed, A. M. (2024). Exploring the effectiveness of augmented reality technology on reading comprehension skills among early childhood pupils with learning disabilities. *Journal of Computers in Education*, *11*, 423–444. https://doi.org/10.1007/s40692-023-00269-9

Şimşek, B., & Direkçi, B. (2023). The effects of augmented reality storybooks on student's reading comprehension. *British Journal of Educational Technology*, *54*(3), 754–772. https://doi.org/10.1111/bjet.13293

Su, X., Cheng, K., Zhang, H., Lee, J., Olson, W., & Froehlich, J. E. (2023). A demonstration of RASSAR: Room accessibility and safety scanning in augmented reality. In *Proceedings of the 25th International ACM SIGACCESS Conference on Computers and Accessibility* (pp. 1–4). ACM. https://doi.org/10.1145/3597638.3614504

Su, Y.-S., Lai, C.-C., Wu, T.-K., & Lai, C.-F. (2022). The effects of applying an augmented reality English teaching system on students' STEAM learning perceptions and technology acceptance. *Frontiers in Psychology*, *13*, 996162. https://doi.org/10.3389/fpsyg.2022.996162

Vygotsky, L. S., & Cole, M. (1978). *Mind in society: Development of higher psychological processes*. Harvard University Press.

Ysseldyke, J., & Bolt, D. M. (2007). Effect of technology-enhanced continuous progress monitoring on math achievement. *School Psychology Review*, *36*(3), 453–467. https://doi.org/10.1080/02796015.2007.12087933

Zhang, S., & Thompson, N. (2004). DIALANG: A Diagnostic Language Assessment System (review). *The Canadian Modern Language Review / La Revue Canadienne Des Langues Vivantes*, *61*(2), 290–293. https://doi.org/10.1353/cml.2005.0011

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