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INTEGRATING AUGMENTED REALITY AND ZERO WASTE CONTENT IN EFL INSTRUCTION: A NEED ANALYSIS STUDY

NADIRA MUTIARA FASYA, SARY SILVHIANY, ERYANSYAH
Universitas Sriwijaya, Palembang, Indonesia
Corresponding author**:** ssilvhiany@unsri.ac.id

Abstract
Environmental literacy is crucial to overcome sustainability issues such as zero waste, especially in educational environments. This study evaluates the needs of students for augmented reality (AR) based zero waste content to improve environmental literacy in an English as a Foreign Language (EFL) context at MAN 2 Palembang. A descriptive quantitative design was employed using a needs analysis approach with 92 eleventh grade students. Data were collected through a questionnaire assessing environmental knowledge, attitudes, material needs, familiarity with AR technology, and the demand for AR-based learning media. Descriptive statistical analysis revealed distinct patterns across five indicators: Environmental Material Needs had the lowest mean score (M = 3.02, SD = 0.73), followed by Environmental Attitude and Responsibility (M = 3.41, SD = 0.34), and Environmental Knowledge and Awareness (M = 3.63, SD = 0.42). In contrast, AR-related indicators received higher mean scores, with AR Technology Knowledge attaining the highest (M = 3.88, SD = 0.39) and the Need for AR Based Learning Media showing strong support (M = 3.78, SD = 0.50). Furthermore, 58.7% of respondents indicated a high need for AR based learning media, while only 6.5% expressed low needs. These findings suggest that integrating zero waste content with AR based learning media can effectively support environmental literacy in EFL education. Practically, the results offer educators and curriculum developers evidence based guidance for creating contextually relevant and enhanced environmental learning materials that align students' technological readiness with their need for meaningful environmental content.

Keywords: augmented reality, environmental literacy, EFL learning, needs analysis, zero waste

Introduction

The Global warming represents a significant and urgent climate crisis. Projections suggest that 2023 and 2024 are likely to be the hottest years recorded, with temperatures nearing the 1.5 degrees Celsius threshold established by the Paris Agreement (Dunstone et al., 2024). A pivotal factor exacerbating this climate crisis is waste disposal. Global waste production is anticipated to increase from 2.1 billion tons in 2023 to 3.8 billion tons by 2050, thereby intensifying the climate emergency (Kaza et al., 2018). Educational institutions are among the largest generators of waste, particularly dry waste such as paper, plastic, food scraps, and packaging materials, rivaling the contributions of households, markets, and industrial sectors (Gusti & Iqbal, 2022). The high-density activities of schoolchildren result in substantial amounts of inorganic waste, which further contributes to environmental pollution.

In Indonesia, approximately 52.9 million school students are projected for the 2024-2025 academic year, generating both organic and inorganic waste on a daily basis (Badan Pusat Statistik, 2025). Schools across Indonesia produce significant quantities of waste daily, predominantly comprising plastic waste, such as food wrappers and bottles around 42.7-42.71%, and organic waste, including leaves and food scraps 24.5-42.3% (Littaqwa et al., 2025). This data highlights that

organic waste, particularly food scraps, constitutes a substantial proportion of the waste generated by schools.

Environmental literacy education centered on the zero-waste movement within educational institutions is essential. The engagement of the school community, particularly students and educators, is vital in tackling waste management challenges within schools (Susandi, 2025). MAN 2 Palembang serves as an illustrative example of an institution that has integrated environmental topics into its curriculum. However, the extent of this integration remains limited and does not explicitly target zero-waste practices. This limitation is concerning, as waste management at MAN 2 continues to face challenges due to various factors, one of which is the insufficient awareness among students. Furthermore, environmental materials are currently available only in Indonesian. Given the increasing global importance of the English language and the fact that MAN 2 offers several bilingual classes, the incorporation of English-language resources would significantly enhance the educational experience and foster greater environmental awareness.

One of the new ways to teach that has come up is Augmented Reality (AR) technology. It appears that it might represent a useful way to combine language instruction with environmental education to make learning more interesting and immersive. Research shows that young learners have a keen interest in environmental topics and they gain more from resources that include visual, auditory, and interactive elements (Jasmine et al., 2025). In language education, AR has been shown to be helpful at making real-world language use and classroom instruction more connected. AR's interactive features significantly boost student motivation and participation in language learning activities (Idul & Syaiful, 2024). Studies indicate that AR can significantly improve language retention and fluency by providing interactive and engaging content (Trisnawati et al., 2025). In addition, AR can adapt to different learning styles, promoting critical thinking and collaboration among students (Kavaklı et al., 2024). Considering these potential benefits, understanding students' specific needs for AR-based zero-waste content becomes essential to designing effective materials that truly enhance both their English proficiency and environmental consciousness.

Despite the recognized potential of AR technology in education and the urgent need for environmental literacy in Indonesia, significant gaps remain in understanding how to effectively integrate AR-based environmental education in EFL settings. While existing studies have explored AR in language learning and environmental education, there is a notable absence of needs analysis studies examining students' perspectives and requirements for AR-based environmental learning materials in Indonesian EFL contexts. Previous research has predominantly focused on teacher perspectives or implementation outcomes, overlooking learners' actual needs before developing interventions . Therefore, this study aims to analyze students' needs for Augmented Reality with zero waste content to support environmental literacy in EFL classrooms at MAN 2 Palembang.

Literature Review

Environmental literacy in education

Environmental literacy constitutes an essential component of education that enables individuals to comprehend the intricate relationships between human activities and natural ecosystems (Fang et al., 2023). This concept extends beyond the acquisition of environmental knowledge to include the development of critical skills and attitudes required to evaluate environmental issues and make informed, responsible decision (Purwandani et al., 2025). Within formal education, environmental literacy plays a vital role in promoting sustainable behavioral change and fostering both individual and collective responsibility for environmental protection.

The development of students' environmental literacy requires an integrated and comprehensive instructional approach that connects learning with real-life situations. Learning

environments should promote inquiry-based activities, experiential learning, and critical dialogue that allow students to engage directly with the complexity of environmental problems (Yadav, 2023). Engaging students in hands-on activities promotes a deeper understanding of environmental challenges and solutions Through such active participation, students move beyond rote learning and develop the ability to analyze, reflect, and apply environmental concepts (Silvhiany et al., 2023). Through such active participation, students move beyond rote learning and develop the ability to analyze, reflect, and apply environmental concepts. This process deepens their awareness of the consequences of human actions and equips them to become environmentally responsible members of society.

Moreover, embedding environmental literacy within the curriculum supports interdisciplinary learning (Rustamova., 2023). Incorporating environmental education into formal curricula is vital for developing eco-literacy (Silvhiany et al. 2024). Programs that emphasize real-world applications and interdisciplinary approaches have proven effective (Vladova, 2023). For instance, lessons on the water cycle in science classes can be linked to discussions on the social and ethical dimensions of water scarcity. EFL textbooks can include environmental themes to raise students' ecological awareness. Through this approach, learners not only improve their language skills but also gain a better understanding of environmental issues. Reading environmental stories, in particular, encourages the development of critical thinking and communicative abilities, helping students grow into more responsible and environmentally conscious individuals (Raphael & Nandanan, 2024). Through this integrated approach, environmental literacy becomes a unifying element across subjects, enriching students' learning experiences and reinforcing the shared responsibility for sustainability.

Zero Waste strategies in educational contexts

Educational institutions play a strategic role in implementing zero waste initiatives because of their high levels of resource use and their capacity to shape pro-environmental behaviors among students, educators, and staff. Effective zero waste implementation generally involves a combination of waste assessment, improvements to facilities, policy formulation, and behavioral change initiatives (Nuojua, 2024). Educational campaigns are vital for raising awareness and motivating participation among students and staff (Alazaiza et al., 2025). Involving students in hands-on projects, such as recycling initiatives, fosters a culture of sustainability and responsibility (Andini et al., 2022). Upgrading facilities to support recycling and composting is crucial. Facility improvements may include the introduction of recycling and composting systems, the substitution of disposable products with reusable options, and the establishment of spaces for repairing or repurposing materials.

The successful adoption of zero waste practices depends on clearly defined responsibilities among all members of the school community, supported by cooperation and collective responsibility. Establishing a formal environmental management system and written policies can provide a framework for sustainability efforts (Mason et al., 2003). Teachers play a central role by incorporating zero waste concepts into instructional activities and modeling sustainable behaviors in the classroom. They design developmentally appropriate learning experiences, maintain learning environments that reflect zero waste principles, and collaborate with other educators to ensure consistency across subjects and grade levels (Rulli et al., 2024). Students are encouraged to move beyond passive participation by assuming leadership roles as agents of change within their schools. Their involvement may include participating in waste audits, proposing solutions to waste-related issues, managing recycling systems, and sharing zero waste messages with peers, families, and the wider community. These activities promote critical thinking, teamwork, and civic responsibility.

Augmented Reality in educational context

Augmented reality (AR) has emerged as an innovative technology with significant potential to transform educational practices by creating immersive and interactive learning environments. Research by Ravichandran et al. (2024) indicates that AR enhances student engagement by providing interactive experiences that increase motivation and active participation. Furthermore, AR enables the customization of learning materials to accommodate diverse learning styles, thereby promoting more inclusive and effective learning processes (Sophia et al., 2024). By integrating digital elements into real-world settings, AR supports learners in comprehending complex concepts more deeply and meaningfully.

The application of AR in education contributes to improved learning outcomes through the integration of virtual and physical environments. This combination creates enriched learning experiences that support better knowledge retention and understanding (Maskana et al., 2024). The interactive and immersive characteristics of AR stimulate students' cognitive engagement and promote the development of higher-order thinking skills, including critical thinking (Hiver et al., 2024). In addition, AR can support instructional strategies such as reading comprehension through video modeling and individualized practice activities. Liu et al. (2023) highlight that AR offers notable benefits, including the visualization of abstract concepts, support for long-term learning, and increased student interest through interactive instructional materials (Shankar et al., 2023). . This combination fosters improved knowledge retention and understanding among students, as these technologies create immersive and interactive learning settings that engage learners more effectively.

Needs analysis in educational technology development

Needs analysis represents a systematic and foundational process in educational technology development, serving as a critical bridge between learner requirements and instructional design decisions. In the context of language education and educational technology integration, needs analysis functions as a methodical investigation into what learners need to know, what they already know, and the gap between these two states (Brown, 2016). This process is particularly crucial when developing innovative technological interventions such as AR-based learning materials, as it ensures that the final product aligns with actual learner needs rather than assumptions about what learners might require.

The importance of needs analysis in educational technology development cannot be overstated. First, it provides an evidence-based foundation for curriculum and material design, ensuring that resources invested in technology development address genuine educational gaps rather than perceived ones (Nation & Macalister, 2020). Second, needs analysis enhances the relevance and effectiveness of learning materials by grounding them in learners' actual contexts, challenges, and goals. When technological interventions are developed without adequate needs analysis, they risk being technologically sophisticated but pedagogically misaligned with learner requirements (Tomlinson, 2012). Third, conducting needs analysis demonstrates respect for learners as stakeholders in their own educational journey, acknowledging that their perspectives, preferences, and self-reported needs are valuable sources of information for instructional design.

Various methods can be employed to conduct needs analysis, each offering distinct advantages depending on the research context and objectives. Questionnaires and surveys represent one of the most commonly used methods, particularly valuable for gathering standardized data from large groups of learners efficiently (Hyland, 2006). These instruments can capture quantitative data about learners' current proficiency levels, attitudes, preferences, and perceived needs, as well as qualitative insights through open-ended questions. Interviews, whether structured, semi-structured, or unstructured, provide opportunities for deeper exploration of

learner needs and allow researchers to probe responses and clarify ambiguities (Long, 2005). Focus group discussions combine the depth of interviews with the interactive dynamics of group settings, enabling researchers to observe how learners collectively articulate and negotiate their needs.

Observation methods offer another valuable approach, particularly for identifying needs that learners may not explicitly articulate or recognize themselves. Classroom observations can reveal gaps between learners' reported needs and their actual behaviors, performance, and engagement patterns. Document analysis, including examination of existing curricula, syllabi, and learning materials, can help identify what content is currently available and where gaps exist. In the context of AR-based educational technology development, needs analysis might also include technology readiness assessments to evaluate learners' access to devices, digital literacy levels, and attitudes toward technology-enhanced learning. Triangulation, or the use of multiple methods in combination, is considered best practice in needs analysis as it provides a more comprehensive and reliable picture of learner needs than any single method could offer.

For this study, the needs analysis approach is particularly relevant as it enables systematic investigation of students' current environmental knowledge and attitudes, their familiarity with AR technology, and their expressed needs for innovative learning materials that integrate environmental content with technological affordances. By grounding the development of AR-based zero waste content in empirical data about student needs, this research ensures that the resulting materials will be contextually appropriate, pedagogically sound, and responsive to the actual requirements of EFL learners at MAN 2 Palembang.

Theoretical framework: integrating environmental literacy, Zero Waste, AR, and EFL

The conceptual framework for this study integrates four interconnected domains: environmental literacy, zero waste education, augmented reality technology, and English as a Foreign Language instruction. This integration is grounded in several complementary theoretical perspectives that collectively explain how AR-based zero waste content can effectively support environmental literacy development within EFL contexts.

At the foundation of this framework lies constructivist learning theory, which posits that learners actively construct knowledge through experiences and interactions with their environment rather than passively receiving information (Vygotsky, 1978; Piaget, 1952). This theoretical lens is particularly relevant to environmental literacy education, which requires learners not only to acquire factual knowledge about environmental issues but also to develop critical thinking skills, values, and attitudes that inform responsible environmental behavior. When applied to AR-based learning, constructivism suggests that the interactive and immersive nature of AR can facilitate deeper engagement with environmental concepts by allowing learners to manipulate virtual objects, observe environmental processes, and experiment with sustainability scenarios in ways that traditional instruction cannot support.

Experiential learning theory (Kolb, 1984) further enriches this framework by emphasizing the role of concrete experiences in learning. According to this theory, effective learning occurs through a cyclical process of experiencing, reflecting, thinking, and acting. AR technology aligns well with experiential learning principles because it enables learners to engage in simulated experiences that approximate real-world environmental challenges. For instance, an AR application demonstrating waste decomposition processes or visualizing the environmental impact of different waste management choices provides concrete experiences that learners can reflect upon, analyze, and apply to their own waste-related behaviors. In the context of zero waste education, experiential learning through AR can make abstract environmental concepts tangible and personally relevant, thereby strengthening the connection between knowledge and action.

The Technology Acceptance Model (TAM), developed by Davis (1989), provides theoretical grounding for understanding how and why students might adopt AR-based learning materials. TAM proposes that two key factors influence technology adoption: perceived usefulness (the degree to which users believe the technology will enhance their performance) and perceived ease of use (the degree to which users believe the technology will be free from effort). For AR-based zero waste content to be effective in supporting environmental literacy, students must perceive it as both useful for their learning goals and sufficiently easy to use. This theoretical perspective underscores the importance of needs analysis in this study; understanding students' current technological readiness and their expectations for AR-based materials directly informs how such materials should be designed to maximize acceptance and utilization.

Content and Language Integrated Learning (CLIL) theory (Coyle et al., 2010) provides the pedagogical rationale for integrating environmental content with English language instruction. CLIL posits that learning a foreign language and learning subject matter content can be mutually reinforcing processes when appropriately integrated. In this framework, environmental literacy serves as the content domain while English serves as the medium of instruction and communication. This dual focus offers several advantages: it provides authentic, meaningful contexts for language use; it enhances motivation by connecting language learning to real-world issues that matter to students; and it promotes deeper cognitive engagement as students must simultaneously process content and language. When AR technology is added to this integration, it further enriches the learning experience by providing multimodal input (visual, auditory, kinesthetic) that supports both content comprehension and language acquisition.

Finally, the Multimedia Learning Theory proposed by Mayer (2009) offers principles for designing effective AR-based instructional materials. This theory suggests that people learn more deeply from combinations of words and pictures than from words alone, provided that the multimedia elements are designed according to specific cognitive principles such as spatial and temporal contiguity, coherence, and personalization. AR technology inherently supports multimedia learning by superimposing digital information (text, images, animations, sounds) onto physical environments. When developing AR-based zero waste content, applying multimedia learning principles ensures that the technological affordances of AR are leveraged in ways that enhance rather than overwhelm cognitive processing.

The synthesis of these theoretical perspectives creates a robust conceptual framework for understanding how AR-based zero waste content can support environmental literacy in EFL contexts. Constructivism and experiential learning explain the learning processes through which students construct environmental knowledge and develop pro-environmental attitudes and behaviors. TAM illuminates the factors affecting students' willingness to engage with AR technology. CLIL theory justifies the integration of environmental content with English language instruction, while multimedia learning theory guides the design of effective AR-based materials. Together, these theories suggest that when AR technology is thoughtfully designed based on sound pedagogical principles and grounded in students' actual needs, it can create powerful learning experiences that simultaneously develop English proficiency, environmental literacy, and technological competence. This integrated theoretical framework provides the conceptual foundation for the needs analysis conducted in this study and will subsequently inform the development of AR-based zero waste content tailored to the specific needs and contexts of EFL learners at MAN 2 Palembang.

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Methodology

Research design and approach of the study

This study adopted a descriptive quantitative research design which appropriate for systematically gather standardized information to describe specific aspects of a given population (Miksza et al., 2023). Descriptive quantitative research allows researchers to quantify variables and analyze patterns through statistical procedures (Deckert & Wilson, 2023). Thus, it is appropriate for investigating students' needs and perceptions concerning educational interventions.

The study employed a needs analysis approach as its methodological framework. Need analysis, as conceptualized by Brown (2016), is a systematic process of gathering information about students' current state, desire goals, and the gaps between them to inform curriculum and material development. In this context, need analysis cover three key dimensions such as students' necessities, the knowledge gap, and what they want to learn. This approach was selected because it provides a learner centered foundation for developing educational imposed assumptions (Toshova & Khasanov, 2023). The need analysis framework enabled the researchers to systematically identify students' perspectives on environmental education, their familiarity with technology, and their preference for learning media before designing AR based material.

Research site and participants

The study was conducted over three months period from July 2025 to September 2025. The research timeline proceeded as follows: July 2025 focused on instrument development and validation; August 2025 encompassed data collection from participants; and September 2025 was dedicated to data analysis and interpretation.

The study was conducted at MAN 2 Palembang, a senior secondary Islamic school where English is taught as a foreign language. MAN 2 Palembang was selected as the research site for several reasons. First, it follows the national curriculum which includes English as compulsory foreign language subject, making it representative of the broader Indonesian EFL context. Second, the school has adequate technological infrastructure to potentially support AR based learning innovations. Third the school is facing challenges related waste managements, making environmental literacy education particularly relevant and urgent for students in this context.

The participants consisted of 92 secondary level EFL students from MAN 2 Palembang. A purposive sampling technique was employed to select participants who met specific inclusion criteria (Makwana et al., 2023). This approach was appropriate because the study required participants who could provide relevant information related to integration of AR technology and environmental content in EFL learning. (Memon et al., 2024). The specific inclusion criteria for participants selection were: (1) enrolment. In eleventh grade at MAN 2 Palembang during the 2024 until 2025 academic year; (2) active participants in regular English language classes; (3) ownership of regular access to a smartphone or gadget device; (4) willingness to participate voluntarily in the study; and (5) provision of informed consent.

Data collection

Data were gathered using a structured questionnaire. The questionnaire development process followed established guidelines for educational research instrument constructions (Artino et al., 2014). The questionnaire examine students' needs across three main dimensions: (1) existing English learning practices, (2) students' awareness and understanding of zero-waste and environmental issues, and (3) their expectations regarding the use of augmented reality as a learning

media. The questionnaire was developed through a systematic five-stage process: (1) literature review and conceptual framework development, (2) item generation, (3) expert validation, (4) pilot testing, and (5) instrument refinement.

The questionnaire was adapted from Kayis et al. (2022) which provide a set of related question regarding zero waste. In addition, for the AR integrated questionnaire is adapted from Chang et al. (2020) as guideline for constructing the questionnaire. The questionnaire primarily employed a Likert scale format to capture quantifiable responses, complemented by several open-ended questions to allow students to express their views more freely. The Likert scale format was selected because it is widely used and validated for measuring attitudes, perceptions, and needs in educational research (Koo & Yang, 2025). The 5-point scale provides sufficient variability in responses while remaining simple enough for participants to understand and use consistently.

Data analysis

The data were analyzed using IBM SPSS Statistics through descriptive techniques, including frequency distributions, percentages, and mean scores, to identify prevailing patterns and priority needs among the respondents (Pallant, 2020). The results were then interpreted to determine areas requiring pedagogical support and technological integration. These findings served as the basis for formulating main considerations in the development of augmented reality based zero waste content aimed at enhancing environmental literacy in EFL classrooms at MAN 2 Palembang.

Research instrument test results

The research instrument test was conducted to determine the validity and reliability of the questionnaire used in this study. The validity test was conducted using the Pearson Product Moment correlation between the score of each item and the total score. The analysis results showed that all 38 statement items had a significant correlation coefficient value with a significance value (Sig. 2-tailed) of less than 0.05, so that all items were declared valid.

Table 1. *Instrument reliability test results*

Cronbach's Alpha	*N of items*
0,853	38

Furthermore, the instrument reliability test was conducted using the Cronbach's Alpha coefficient and obtained a value of 0.853, which is above the minimum limit of 0.70. These results indicate that the research instrument has a high and consistent level of reliability, so it is suitable for use as a data collection tool in this study.

Findings

This section presents the findings of the needs analysis conducted to explore students' needs for Augmented Reality (AR) based zero waste content to support environmental literacy in EFL classrooms at MAN 2 Palembang. The findings are organized systematically according to the following research questions that guided this study:

1. What are students' current levels of environmental knowledge, attitudes, and awareness of zero waste concepts?
2.. What are students' familiarity with and readiness to engage with Augmented Reality technology in learning?

3. To what extent do students express a need for AR-based learning media to support their environmental literacy development?

Each research question is addressed in its respective subsection below, with detailed analysis and interpretation of the quantitative data collected through the structured questionnaire.

Students' environmental knowledge, attitudes, and awareness

The first research question examined students' current levels of environmental knowledge, attitudes toward environmental responsibility, and their awareness of zero waste concepts. This question was addressed through analysis of three distinct indicators: Environmental Knowledge and Awareness, Environmental Attitude and Responsibility, and Environmental Material Needs. Table 1 presents the descriptive statistics for these indicators.

Table 2. *Descriptive Statistics for Environmental Literacy Indicators*

Indicators	*M*	*SD*
Environmental Knowledge and Awareness	3.63	0.42
Environmental Attitude and Responsibility	3.41	0.34
Environmental Material Needs	3.02	0.73

As shown in Table 2, the Environmental Knowledge and Awareness indicator yielded a mean score of 3.63 (SD = 0.42), indicating that students possess a moderate to high level of foundational knowledge about environmental issues and demonstrate awareness of environmental challenges in their immediate context. This finding suggests that students are generally familiar with basic environmental concepts and recognize the importance of environmental protection. The relatively low standard deviation indicates consistency across respondents, meaning that most students share a similar baseline understanding of environmental topics.

However, knowledge alone does not guarantee pro-environmental behavior. The Environmental Attitude and Responsibility indicator, which measures students' affective orientation toward environmental issues and their sense of personal responsibility for environmental stewardship, showed a mean score of 3.41 (SD = 0.34). This score, while still in the moderate range, is notably lower than the knowledge indicator. The relatively smaller standard deviation suggests that students' attitudes are fairly uniform, yet the moderate mean indicates that although students acknowledge environmental concerns, their sense of personal responsibility and emotional commitment to environmental action remains underdeveloped. This gap between knowing and caring represents an important pedagogical challenge, as environmental literacy requires not only cognitive understanding but also affective engagement that motivates responsible action.

Most critically, the Environmental Material Needs indicator recorded the lowest mean score of 3.02 (SD = 0.73). This indicator assessed students' perceptions of the adequacy, relevance, and contextual appropriateness of the environmental content they have encountered in their learning experiences. The lower mean score suggests that students feel their current exposure to environmental materials, particularly those addressing zero waste and sustainability, is insufficient or not sufficiently connected to their lived experiences and local environmental challenges. The higher standard deviation compared to other environmental indicators points to greater variability in students' perceptions of material adequacy, possibly reflecting differences in prior exposure to environmental education or varying levels of engagement with environmental topics outside the classroom.

Taken together, these findings reveal a clear pattern: students have acquired basic environmental knowledge and demonstrate moderate environmental awareness, yet they express a significant need for more comprehensive, contextually relevant, and engaging environmental learning materials. This gap between conceptual knowledge and material adequacy highlights the necessity of developing instructional resources that not only convey information but also connect environmental concepts to students' daily lives and local sustainability challenges, such as the waste management issues prevalent in Palembang.

Students' Familiarity and Readiness for AR Technology

The second research question investigated students' familiarity with Augmented Reality technology and their readiness to engage with AR as a learning medium. Understanding students' technological readiness is essential for designing AR-based interventions that are pedagogically feasible and aligned with students' existing competencies. Table 2 presents the descriptive statistics for the AR Technology Knowledge indicator.

Table 3. *Descriptive statistics for AR technology knowledge*

Indicator	M	SD
Augmented Reality Technology Knowledge	3.88	0.39

As presented in Table 3, the AR Technology Knowledge indicator achieved the highest mean score among all measured indicators, with M = 3.88 (SD = 0.39). This notably high score indicates that students possess a considerable degree of familiarity with AR technology and demonstrate confidence in their ability to engage with technology-enhanced learning environments. The low standard deviation suggests a high degree of consistency across the sample, meaning that the vast majority of respondents share similar levels of technological familiarity and readiness.

This finding is particularly significant in the context of Indonesian secondary education, where digital literacy has been increasingly prioritized in recent years. Many students at MAN 2 Palembang have been exposed to various forms of educational technology through their coursework, personal smartphone use, and engagement with digital media platforms. The high mean score suggests that students are not only aware of AR technology but may have also encountered AR applications in gaming, social media filters, or other informal contexts. This prior exposure reduces potential barriers to adoption and indicates that students are likely to perceive AR-based learning materials as accessible, relevant, and aligned with their digital competencies.

Moreover, the combination of high technological readiness and lower environmental content adequacy (as noted in RQ1) creates a unique pedagogical opportunity. Students appear well-equipped to engage with technologically sophisticated learning tools, yet they lack access to sufficiently rich and contextually relevant environmental content. This imbalance suggests that the integration of AR technology with zero waste content could address a clear instructional gap by leveraging students' existing technological competence to deliver more engaging and meaningful environmental education.

Students' Need for AR-Based Learning Media

The third research question sought to determine the extent to which students express a need for AR-based learning media to support their environmental literacy development. This question directly addresses the central aim of the needs analysis and provides evidence for the demand for innovative, technology-integrated instructional materials. Two forms of analysis were conducted

to answer this question: descriptive statistics for the Need for AR-Based Learning Media indicator, and categorical distribution of overall need levels.

Table 4. *Descriptive statistics for need for AR-based learning media*

Indicators	***M***	***SD***
Need for AR-Based Learning Media	3.78	0.50

Table 4 shows that the Need for AR-Based Learning Media indicator achieved a mean score of 3.78 (SD = 0.50), placing it among the highest indicators measured in this study. This high mean score demonstrates that students strongly endorse the integration of AR technology into their environmental learning experiences and perceive such media as potentially valuable for enhancing their understanding and engagement. The moderate standard deviation indicates that while most students express strong interest in AR-based learning, there is some variation in the intensity of this need, likely reflecting individual differences in learning preferences, prior experiences with technology, or expectations regarding instructional innovation.

To further understand the distribution of student needs, respondents were categorized into three need levels based on their overall questionnaire responses: High Needs (corresponding to Agree and Strongly Agree responses), Moderate Needs (Neutral responses), and Low Needs (Disagree responses). Table 4 presents the frequency distribution across these categories.

Table 5. *Distribution of respondents by need category*

Needs Category	**Frequency**	**Percentage**
High Needs (Agree + Strongly Agree)	54	58.7
Moderate Needs (Neutral)	32	34.8
Low Needs (Disagree)	6	6.5
Total	92	100

As illustrated in Table 5, a substantial majority of respondents, representing 58.7% of the sample (n = 54), fall into the High Needs category. These students explicitly agree or strongly agree that they require AR-based learning media to support their environmental literacy development. This finding is particularly noteworthy, as it reflects not merely passive interest but active demand for innovative instructional approaches that combine environmental content with immersive technology. An additional 34.8% of respondents (n = 32) are classified in the Moderate Needs category, indicating that they are open to the idea but may require further exposure or convincing before fully endorsing AR-based learning. Only a small minority, 6.5% (n = 6), expressed low needs, suggesting minimal resistance to the proposed integration of AR technology.

The distribution presented in Table 4 reinforces the quantitative findings from Table 3 and provides clear evidence of widespread student interest in AR-based environmental learning. The fact that nearly 60% of students express high needs indicates strong alignment between students' learning preferences and the proposed pedagogical innovation. Furthermore, when high and moderate need categories are combined, over 93% of students show at least some level of receptiveness to AR-based learning media. This overwhelming endorsement provides a strong empirical foundation for developing AR-based zero waste content tailored to the needs and expectations of EFL learners at MAN 2 Palembang.

Collectively, the findings from RQ3 demonstrate that students perceive AR-based learning media as a valuable and desirable addition to their educational experience. This expressed need, combined with students' high technological readiness (RQ2) and their identified gaps in environmental content adequacy (RQ1), creates a compelling case for the development of AR-based zero waste instructional materials that can effectively enhance environmental literacy while capitalizing on students' existing digital competencies and intrinsic motivation for technology-enhanced learning.

Descriptive statistical analysis per indicator

Table 6. *Mean and Standard Deviation per Indicator*

Indicator	Mean	SD
Environmental Knowledge and Awareness	3.63	0.42
Environmental Attitude and Responsibility	3.41	0.34
Environmental Material Needs	3.02	0.73
Augmented Reality Technology Knowledge	3.88	0.39
The Need for Augmented Reality-Based Learning Media	3.78	0.50

To obtain a more comprehensive picture of needs, further analysis was conducted based on five need indicators, namely: (1) Environmental Knowledge and Awareness, (2) Environmental Attitude and Responsibility, (3) Environmental Material Needs, (4) Augmented Reality (AR) Technology Knowledge, and (5) Augmented Reality-Based Learning Media Needs. The analysis results show that the Environmental Material Needs indicator has the lowest average value, namely M = 3.02 (SD = 0.73). Furthermore, the Environmental Attitude and Responsibility indicator had a mean value of M = 3.41 (SD = 0.34), which indicates that students' concern for the environment is in the moderate category. The Environmental Knowledge and Awareness indicator obtained a mean value of M = 3.63 (SD = 0.420). The Augmented Reality-Based Learning Media Needs indicator showed a mean value of M = 3.78 (SD = 0.50), while the AR Technology Knowledge indicator obtained the highest mean value, namely M = 3.88 (SD = 0.39). These results indicate that students are relatively familiar with AR technology and have a positive perception of its use in learning.

Distribution of respondents' needs categories

Table 6 *Distribution of respondents' needs categories*

Needs Category	**Frequency**	**Percentage (%)**
High Needs (Agree + Strongly Agree)	54	58.7
Moderate Needs (Neutral)	32	34.8
Low Needs (Disagree)	6	6.5
Total	92	100

As many as 58.7% of respondents were in the high need category for augmented reality-based learning media, while 34.8% were in the medium category, and only 6.5% of respondents were in the low need category.

Discussion

The discussion based on indicators provides a more comprehensive picture of student needs. The Environmental Material Needs indicator had the lowest mean score compared to the other indicators. Previous studies have shown that environmental learning becomes more meaningful when content is closely linked to learners' real-life contexts and practical challenges (Ardoin et al., 2020). This finding indicates that students still need reinforcement of environmental material, particularly regarding zero waste issues. The low mean score for this indicator may be due to a lack of depth in the material, limited contextual examples, or a delivery method that fails to connect environmental concepts to the realities of students' lives.

The Environmental Attitude and Responsibility indicator fell into the moderate category. This indicates that although students have developed an attitude of environmental concern, this attitude has not yet fully developed into responsibility and concrete behavior. This aligns with research indicating that environmental education should go beyond cognitive understanding and intentionally foster pro-environmental attitudes, values, and character through experiential and reflective learning activities (Edwin et al., 2025). Targeted educational interventions have been shown to effectively strengthen students' environmental responsibility, particularly when learning activities incorporate learning material that promote sustained engagement with environmental sustainability (Loor et al., 2024). This situation indicates that environmental learning needs to be designed not only to increase knowledge but also to shape environmentally conscious attitudes and character through meaningful learning experiences.

The Environmental Knowledge and Awareness indicator showed a higher mean score than the previous two indicators. This finding indicates that students have a basic understanding of environmental issues. However, this understanding remains conceptual and requires reinforcement through more applied and visual learning so that students can internalize environmental concepts more deeply (Fang et al., 2023). The indicators for Knowledge of Augmented Reality Technology and Need for Augmented Reality-Based Learning Media achieved the highest mean scores. This indicates that students are relatively familiar with AR technology and have a positive perception of its application in learning. High scores on these two indicators reflect students' readiness to embrace technology-based learning media innovations and also open up opportunities for the development of more interactive and engaging learning media.

Need levels based on indicators

A comparison of average scores across indicators indicates that students' most pressing needs relate to environmental content, followed by environmental attitudes and responsibilities, while readiness for AR-based learning technologies and media is relatively high. This pattern highlights a clear imbalance between students' cognitive and affective needs for environmental content and their readiness to engage with advanced learning technologies. Similar findings have been reported in previous research (Radianti et al., 2020) which emphasizes that technological readiness alone does not guarantee meaningful learning outcomes without well-structured and contextually relevant content

These results indicate a gap between content needs and media readiness. Although students demonstrated familiarity with and openness to AR-based learning tools, they still needed reinforcement of environmental material relevant to real-life contexts and sustainability challenges. Research in environmental education indicates that learning is more effective when environmental issues are presented in ways that are authentic, locally relevant, and connected to students' everyday experiences (Silvhiany et al., 2023). Without such contextualization, students' understanding tends to remain conceptual and may not translate into responsible environmental behavior (Putri et al.,

2024). Therefore, effective learning development should focus on integrating meaningful and contextual environmental materials with AR-based learning media to bridge this gap

The use of AR-based media is expected to not only enhance students' understanding of environmental concepts but also contribute to the development of stronger environmental attitudes and awareness. Studies show that interactive and immersive learning environments can positively influence learners' affective responses, including motivation, attitudes, and pro-environmental awareness, which are essential for fostering long-term environmental responsibility (Wu et al., 2023). Thus, integrating AR-based media with well-designed environmental materials offers a promising approach to addressing the knowledge and attitude gap in environmental education.

Distribution of need categories

The analysis of the distribution of need categories shows that the majority of respondents have a high need for augmented reality-based learning media. Fifty-eight percent of respondents agreed or strongly agreed, indicating that AR-based learning media is seen as a crucial need to support the learning process. The high percentage in this category demonstrates students' interest and readiness to utilize innovative technology in learning. Meanwhile, 34.8% of respondents fell into the moderate need category, indicating that some students are still considering or have not yet fully realized the urgency of using this media. Only 6.5% of respondents fell into the low need category, indicating that resistance to AR-based learning media is relatively low. These findings confirm that students generally have a need for and a positive perception of the development of augmented reality-based learning media, making it feasible to develop and implement it in their learning.

Limitations and future research directions

This study offers significant insights into students' needs for augmented reality (AR)-based environmental learning materials; however, several limitations warrant acknowledgment, particularly those related to the methodological choices implemented during the research design.

Firstly, in terms of research design, this study utilized a descriptive quantitative approach through a cross-sectional survey. Although this design was suitable for capturing students' self-reported needs at a specific point in time, it precludes causal inferences and does not facilitate an examination of how needs may evolve over time. The cross-sectional nature of the study indicates that the findings represent a snapshot of student needs in early 2025 and may not accurately reflect long-term trends or seasonal variations in environmental awareness. Future research could benefit from employing longitudinal designs to monitor changes in students' environmental literacy and technology acceptance across multiple time points, particularly before and after exposure to AR-based environmental education interventions.

Secondly, regarding the sampling strategy, this study implemented purposive sampling to select 92 eleventh-grade students from MAN 2 Palembang. While this sample size was sufficient for descriptive statistical analysis and was representative of the target population at this specific institution, the findings may not be generalizable to students at other educational settings, different grade levels, or various geographic contexts. The decision to focus exclusively on eleventh-grade students was intentional, as this age group typically possesses more developed critical thinking skills and greater technological literacy; however, this also implies that the findings cannot be readily extended to younger or older learners. Furthermore, the concentration on a single school in Palembang restricts the geographic and institutional diversity of the sample. Future research should adopt probability sampling techniques across multiple schools in various Indonesian regions to enhance the generalizability of the findings. Comparative studies investigating urban

versus rural contexts, diverse socioeconomic backgrounds, and various types of educational institutions (public versus private, religious versus secular) would contribute to a more comprehensive understanding of environmental learning needs.

Conclusion

This study aimed to analyze students' needs for Augmented Reality (AR) with zero waste content to support environmental literacy in EFL classrooms at MAN 2 Palembang. Through systematic needs analysis involving 92 eleventh-grade students, three key findings emerged that directly address the research questions. First, regarding students' current environmental knowledge, attitudes, and awareness, the results reveal that while students possess moderate to high environmental knowledge (M = 3.63), their environmental attitudes and responsibility remain moderate (M = 3.41), and most critically, they identify significant inadequacies in environmental material needs (M = 3.02), indicating a gap between conceptual knowledge and contextually relevant content. Second, concerning technological readiness, students demonstrated notably high familiarity with AR technology (M = 3.88), with low variance indicating consistent competence across the sample, suggesting minimal technological barriers to implementation. Third, regarding demand for AR-based learning media, an overwhelming 93% of students expressed moderate to high needs (M = 3.78), with 58.7% specifically indicating high needs, providing compelling evidence of student receptiveness to this pedagogical innovation. Therefore, these findings reveal a clear opportunity: students possess high technological readiness and express strong interest in AR based learning, yet they identify significant gaps in environmental content adequacy, creating an optimal context for developing AR-based zero waste materials that can simultaneously address content inadequacies and leverage students' technological strengths.

These findings carry important theoretical, practical, and policy implications. Theoretically, this study validates the critical role of needs analysis in educational technology development and provides empirical support for technology acceptance models, constructivist learning theories, and CLIL approaches in Indonesian EFL contexts, while extending AR scholarship by prioritizing learner perspectives over implementation outcomes. Practically, the identified content gap directs educators and curriculum developers to create contextually relevant zero waste materials connected to local sustainability challenges in Palembang, while the high technological readiness indicates schools can confidently invest in A -based technologies without extensive prerequisite training, though implementation should prioritize pedagogical design over technological novelty. The moderate environmental attitudes suggest interventions must explicitly target affective and behavioral dimensions through interactive AR features that promote reflection, values clarification, and connections between knowledge and personal decision-making. From a policy perspective, specific actions are recommended at three levels: institutionally, schools should establish environmental education working groups, allocate dedicated budgets for AR materials, implement school-wide zero waste initiatives providing authentic language learning contexts, and develop assessment policies evaluating both language proficiency and environmental literacy competencies; at the district level, authorities should develop shared AR material repositories, provide systematic professional development for EFL teachers, establish partnerships with environmental organizations and technology companies, and create incentive structures rewarding successful integration; nationally, the Ministry of Education should revise English teaching standards to explicitly include environmental literacy outcomes, support development of Indonesian-language AR platforms, fund large-scale R&D initiatives for evidence-based materials, and establish quality standards for educational AR applications.

Future research direction

Future research should extend beyond the current needs analysis to include design-based development and effectiveness studies examining whether AR based materials improve environmental literacy and English proficiency outcomes; pedagogical optimization research investigating effective balances between language-focused and content-focused activities; sustainability and scalability studies exploring resources, supports, and conditions necessary for sustained implementation across diverse school contexts; longitudinal research tracking whether classroom learning translates into sustained pro-environmental behaviors; and cross-cultural comparative studies examining how AR based environmental education functions in different contexts. By responding to the empirical evidence generated through this needs analysis and implementing the recommendations outlined above, educators, administrators, and policymakers can work toward creating more engaging, effective, and meaningful environmental education that simultaneously develops English proficiency, environmental literacy, and responsible citizenship among Indonesia's youth. As global environmental challenges intensify, innovations such as AR based zero waste education represent promising pathways toward fostering the knowledge, attitudes, and behaviors necessary for a sustainable future.

Disclosure statement

No potential conflict of interest was reported by the authors.

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