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THE ROLE OF AUGMENTED REALITY AND VIRTUAL REALITY IN ENHANCING ECOLOGICAL LITERACY AND PRO-ENVIRONMENTAL BEHAVIOR: A SYSTEMATIC LITERATURE REVIEW

Peran Augmented Reality dan Virtual Reality dalam Meningkatkan Literasi Ekologis dan Perilaku Pro-Lingkungan: Sebuah Tinjauan Literatur Sistematis

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ABSTRACT

Environmental problems such as climate change, pollution, ecosystem degradation, and biodiversity loss have become global challenges that require effective environmental education. The development of digital technology has provided new opportunities to improve learning through the use of Augmented Reality (AR) and Virtual Reality (VR). These technologies offer interactive and immersive learning experiences that can support the development of ecological literacy and pro-environmental behavior among learners. This study aims to examine the role of AR and VR in improving ecological literacy and pro-environmental behavior through a systematic literature review. The reviewed articles were collected from national and international publications published between 2020 and 2025. The results show that AR and VR have a positive impact on students' understanding of environmental concepts, learning motivation, ecological awareness, environmental empathy, and pro-environmental behavior. Virtual Reality is commonly used for environmental simulations, climate change education, and ecosystem exploration, while Augmented Reality is widely used for visualizing environmental concepts and supporting interactive learning activities. However, several challenges remain, including limited infrastructure, high technology costs, and the need to improve teachers' digital competencies. Overall, AR and VR have great potential to support innovative environmental education and promote sustainable behavior among learners.

ABSTRAK

Permasalahan lingkungan seperti perubahan iklim, pencemaran, degradasi ekosistem, dan hilangnya keanekaragaman hayati menjadi tantangan global yang memerlukan penguatan pendidikan lingkungan hidup. Perkembangan teknologi digital telah membuka peluang baru dalam pembelajaran melalui pemanfaatan Augmented Reality (AR) dan Virtual Reality (VR). Teknologi ini menawarkan pengalaman belajar yang interaktif, kontekstual, dan imersif sehingga dapat mendukung pengembangan literasi ekologis dan perilaku pro-lingkungan peserta didik. Penelitian ini bertujuan untuk mengkaji peran AR dan VR dalam meningkatkan literasi ekologis dan perilaku pro-lingkungan melalui pendekatan tinjauan literatur sistematis. Artikel yang dianalisis diperoleh dari berbagai publikasi nasional dan internasional yang terbit pada periode 2020–2025. Hasil kajian menunjukkan bahwa AR dan VR memberikan dampak positif terhadap pemahaman konsep lingkungan, motivasi belajar, kesadaran ekologis, empati terhadap lingkungan, serta perilaku pro-lingkungan peserta didik. Virtual Reality lebih banyak dimanfaatkan untuk simulasi lingkungan, pendidikan perubahan iklim, dan eksplorasi ekosistem, sedangkan Augmented Reality banyak digunakan untuk memvisualisasikan konsep-konsep lingkungan dan mendukung aktivitas pembelajaran yang interaktif. Meskipun demikian, implementasi kedua teknologi tersebut masih menghadapi berbagai kendala, seperti keterbatasan infrastruktur, tingginya biaya teknologi, dan perlunya peningkatan kompetensi digital pendidik. Secara keseluruhan, AR dan VR memiliki potensi yang besar sebagai media pembelajaran inovatif dalam mendukung pendidikan lingkungan hidup dan mendorong terbentuknya perilaku berkelanjutan pada peserta didik.

INTRODUCTION

Global environmental issues such as climate change, environmental pollution, ecosystem degradation, deforestation, and biodiversity loss indicate that the world is facing increasingly complex ecological challenges. The impacts of these environmental problems extend beyond ecological systems and affect social, economic, health, and human well-being dimensions. Therefore, strategic efforts are needed to enhance public awareness of environmental conservation and encourage the development of sustainable behaviors that support environmental sustainability.

One of the most effective approaches to addressing these challenges is through environmental education. Environmental education plays a crucial role in developing knowledge, attitudes, skills, and responsible behaviors toward the environment. Through environmental education, learners are expected to understand the relationship between humans and nature, identify environmental problems, and actively participate in environmental conservation efforts. In this context, ecological literacy has emerged as an essential competency, reflecting an individual's ability to understand ecological principles and apply them in everyday life to promote environmental sustainability.

Despite its importance, environmental education continues to face several challenges. Environmental learning is often dominated by conventional teaching approaches that emphasize theoretical knowledge rather than practical experiences. As a result, learners frequently encounter

difficulties in connecting environmental concepts with real-world environmental issues. Consequently, increased environmental knowledge does not always lead to greater ecological awareness or positive behavioral changes. This situation highlights the need for innovative learning approaches that can provide more contextual, engaging, and meaningful learning experiences.

The rapid advancement of digital technology has created new opportunities to transform environmental education. Among the emerging educational innovations are immersive technologies such as Augmented Reality (AR) and Virtual Reality (VR). These technologies enable learners to interact with virtual objects and simulated environments that closely resemble real-world conditions, thereby enhancing learning experiences. Through AR and VR, learners can explore ecosystems, visit conservation areas, observe the impacts of climate change, and study biodiversity in immersive and interactive ways that would otherwise be difficult to experience directly (Ladykova et al., 2024; Hajj-Hassan et al., 2024).

Previous studies have demonstrated that the integration of AR and VR in education can positively influence learning processes and outcomes. These technologies have been found to increase learning motivation, student engagement, conceptual understanding, and overall learning experiences (Safitri et al., 2025; Chen et al., 2025). In environmental education, immersive learning experiences can help learners better understand the consequences of environmental problems and foster deeper ecological awareness and environmental empathy (Hurrell et al., 2024; Mendoza et al., 2025).

Beyond improving conceptual understanding, AR and VR also have the potential to promote pro-environmental behavior. Pro-environmental behavior refers to actions undertaken by individuals to minimize negative impacts on the environment and contribute to environmental sustainability. Several studies have reported that immersive virtual experiences, such as simulations of climate change, pollution, and ecosystem degradation, can enhance learners' intentions and commitments to engage in environmentally responsible actions in their daily lives (Sahabuddin et al., 2024; Xiong et al., 2024; Teh et al., 2025).

Although previous studies have reported the educational benefits of Augmented Reality (AR) and Virtual Reality (VR) in environmental learning, existing review studies have primarily focused on specific aspects of immersive technologies. For example, previous reviews have examined the effectiveness of AR in environmental education (Ladykova et al., 2024; Simon et al., 2025), while other studies have investigated the role of digital technologies in promoting sustainability awareness (Hajj-Hassan et al., 2024). In addition, several empirical studies have explored the influence of VR on environmental attitudes and behavioral intentions (Hurrell et al., 2024; Sahabuddin et al., 2024). However, these studies tend to examine either cognitive outcomes, such as environmental knowledge and concept understanding, or affective outcomes, such as environmental awareness and attitudes, separately.

More importantly, there remains a lack of comprehensive review studies that synthesize evidence on how both AR and VR contribute simultaneously to the development of ecological literacy and pro-environmental behavior. Ecological literacy and pro-environmental behavior represent two interconnected yet distinct educational outcomes, encompassing cognitive, affective, and behavioral dimensions of environmental learning. Existing reviews rarely integrate these dimensions within a single analytical framework, making it difficult to understand the broader educational contribution of immersive technologies to environmental education.

Therefore, this study addresses this gap by conducting a systematic literature review of recent studies published between 2020 and 2025 that investigate the role of AR and VR in enhancing ecological literacy and fostering pro-environmental behavior. By synthesizing findings across different educational contexts and learner populations, this review provides a more comprehensive understanding of the educational potential of immersive technologies in supporting environmental sustainability and environmental citizenship.

METHODS

This study employed a Systematic Literature Review (SLR) approach to examine the role of Augmented Reality (AR) and Virtual Reality (VR) in enhancing ecological literacy and pro-environmental behavior. The SLR method was selected because it enables researchers to systematically identify, evaluate, and synthesize findings from previous studies, thereby providing a comprehensive understanding of a particular research topic.

The literature search was conducted using several national and international scientific databases, including Google Scholar, Scopus-indexed journals, ScienceDirect, SpringerLink, Taylor & Francis Online, and ERIC. The search process was carried out between January and May 2026 using combinations of the following keywords: “Augmented Reality,” “Virtual Reality,” “Environmental Education,” “Ecological Literacy,” “Environmental Literacy,” “Sustainability Education,” and “Pro-Environmental Behavior.”

The inclusion criteria for article selection were as follows:

1. Articles published between 2020 and 2025.
2. Studies focusing on the application of Augmented Reality (AR) and/or Virtual Reality (VR) in environmental education contexts.
3. Full-text articles available in English or Indonesian.
4. Empirical studies, experimental studies, case studies, or review articles relevant to ecological literacy, environmental awareness, or pro-environmental behavior.
5. Articles published in peer-reviewed scientific journals.

The exclusion criteria included:

1. Articles published before 2020.
2. Studies unrelated to environmental education.
3. Conference abstracts, editorials, book reviews, and non-peer-reviewed publications.
4. Articles with insufficient methodological information or inaccessible full texts.

The article selection process involved three stages. First, potentially relevant articles were identified through database searches using the selected keywords. Second, duplicate records were removed, and titles and abstracts were screened according to the inclusion criteria. Third, the remaining articles were examined in full text to determine their relevance to the objectives of the study.

The selected articles were analyzed using thematic analysis. This approach was employed to identify recurring themes, patterns, and findings related to the educational impacts of AR and VR. The analysis focused on four major themes: (1) the contribution of AR and VR to ecological literacy, (2) the influence of AR and VR on learning motivation and engagement, (3) the role of AR and VR in fostering pro-environmental behavior, and (4) the challenges and limitations of implementing immersive technologies in environmental education.

The findings from the selected studies were subsequently synthesized and interpreted to provide a comprehensive overview of the potential and effectiveness of immersive technologies in supporting environmental education and promoting sustainable behavior among learners.

RESULTS

The literature search identified a number of studies related to the use of Augmented Reality (AR) and Virtual Reality (VR) in environmental education. After applying the inclusion and exclusion criteria, the selected articles were reviewed and analyzed to identify patterns, trends, and key findings regarding the contribution of immersive technologies to ecological literacy and pro-environmental behavior.

The reviewed studies were conducted in different countries and educational contexts, involving participants from primary schools, secondary schools, and higher education institutions. The studies employed various research designs, including experimental studies, quasi-experimental studies, case studies, and systematic reviews. Table 1 presents the characteristics of the studies included in this review.

Table 1. Characteristics of the Reviewed Studies

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No.	Author(s)	Year	Country	Technology	Participants	Main Findings
1	Chen et al.	2025	China	AR & VR	University students	Improved environmental literacy and learning motivation.
2	Hurrell et al.	2024	United Kingdom	VR	High school students	Enhanced climate change awareness and pro-environmental behavioral intentions.
3	Sahabuddin et al.	2024	Indonesia	VR	University students	Increased pro-environmental behavior through immersive environmental simulations.
4	Öztürk	2023	Türkiye	AR	Secondary school students	Improved environmental knowledge and attitudes.
5	Ladykova et al.	2024	Various countries	AR	Review studies	AR effectively enhanced student engagement and environmental concept understanding.
6	Xiong et al.	2024	China	VR	Undergraduate students	Strengthened environmental responsibility and behavioral intentions.
7	Teh et al.	2025	Malaysia	VR	Students	Immersive learning experiences promoted sustainable behavior.
8	Safitri et al.	2025	Indonesia	AR	University students	Increased learning outcomes and environmental awareness.

As shown in Table 1, the reviewed studies indicate a growing interest in the application of AR and VR in environmental education. The findings consistently demonstrate the positive impact of immersive technologies on learners' understanding of environmental concepts, engagement in learning activities, and environmental awareness. Furthermore, several studies reported that immersive experiences can contribute to the development of pro-environmental attitudes and behaviors.

To provide a clearer understanding of the major findings, the results were synthesized into several thematic categories. Table 2 summarizes the main themes identified from the reviewed studies and their corresponding findings.

Table 2. Synthesis of Research Findings by Theme

Theme	Key Findings	References
Ecological Literacy	AR and VR facilitate the visualization of complex environmental concepts, leading to improved understanding of ecological systems and environmental issues.	Chen et al. (2025); Öztürk (2023)
Learning Motivation and Engagement	Immersive technologies increase student motivation, participation, engagement, and interest in environmental learning.	Ladykova et al. (2024); Safitri et al. (2025)
Environmental Awareness	Simulated environmental experiences foster environmental empathy and awareness.	Hurrell et al. (2024); Mendoza et al. (2025)
Pro-Environmental Behavior	AR and VR encourage environmentally responsible actions and behavioral intentions.	Sahabuddin et al. (2024); Xiong et al. (2024); Teh et al. (2025)
Implementation Challenges	High costs, limited infrastructure, insufficient teacher training, and technological accessibility remain significant barriers.	Hajj-Hassan et al. (2024); Husamah et al. (2025)

The thematic synthesis revealed five major themes: (1) enhancement of ecological literacy, (2) improvement of learning motivation and engagement, (3) development of environmental awareness, (4) promotion of pro-environmental behavior, and (5) challenges in implementing immersive technologies. These themes form the basis of the following discussion.

To further examine the educational potential of immersive technologies, a comparison between Augmented Reality and Virtual Reality was conducted. The comparison focuses on their characteristics, educational benefits, and implementation requirements in environmental education contexts, as presented in Table 3.

Table 3. Comparison of Augmented Reality and Virtual Reality in Environmental Education

Aspect	Augmented Reality (AR)	Virtual Reality (VR)
Concept Visualization	Very High	High
Interactivity	High	Very High
Environmental Simulation	Moderate	Very High
Environmental Empathy Development	Moderate	Very High
Learning Accessibility	High	Moderate
Implementation Cost	Relatively Low	Relatively High
Hardware Requirements	Smartphone or Tablet	VR Headset and Supporting Devices
Classroom Integration	Easier	More Complex
Learning Experience	Interactive	Fully Immersive

The comparison indicates that both AR and VR offer significant educational benefits. AR is particularly effective for visualizing environmental concepts and supporting classroom instruction, whereas VR provides highly immersive experiences that can strengthen environmental awareness and pro-environmental behavior.

DISCUSSION

1. AR and VR for Enhancing Ecological Literacy

The findings of this review indicate that Augmented Reality (AR) and Virtual Reality (VR) have considerable potential to enhance learners' ecological literacy. Ecological literacy refers to an individual's capacity to understand ecological principles and apply such understanding to environmental decision-making and sustainable practices (Orr, 1992). Across the reviewed studies, AR and VR were found to facilitate the visualization of environmental phenomena that are often difficult to observe directly, including ecosystem interactions, biodiversity dynamics, climate change processes, and environmental degradation (Chen et al., 2025; Öztürk, 2023).

The positive impact of AR and VR on ecological literacy can be interpreted through the lens of constructivist learning theory. Constructivism posits that knowledge is actively constructed through learners' interactions with their environment rather than passively transmitted from teacher to student. Learning becomes more meaningful when individuals engage in authentic experiences, explore phenomena, and connect new information with their prior knowledge.

The immersive characteristics of AR and VR align closely with these principles. Through three-dimensional visualization, interactive simulations, and virtual exploration of environmental systems, learners are able to actively investigate ecological phenomena rather than merely receive information through lectures or textbooks. For example, virtual simulations of ecosystems allow learners to observe relationships among organisms, environmental changes, and ecological processes in real time. Such experiences encourage learners to formulate explanations, evaluate environmental consequences, and construct their own understanding of ecological systems.

The empirical findings reviewed in this study provide evidence supporting these theoretical assumptions. Several studies reported that learners who engaged with AR- and VR-based environmental learning demonstrated greater conceptual understanding and environmental literacy than those participating in conventional instruction (Öztürk, 2023; Chen et al., 2025). Similarly, Ladykova et al. (2024) found that immersive

visualization enhanced learners' comprehension of complex environmental concepts by making abstract ecological processes more concrete and observable.

These findings suggest that the effectiveness of immersive technologies is not solely attributable to their novelty or technological appeal but also to their ability to facilitate active knowledge construction, a central principle of constructivist learning.

Furthermore, constructivist perspectives emphasize the importance of contextualized learning. AR and VR enable learners to experience environmental problems within realistic contexts, such as climate change impacts, biodiversity loss, and ecosystem degradation. By situating learning within meaningful environmental scenarios, immersive technologies help learners connect scientific knowledge with real-world environmental challenges. This contextualization may explain why several studies reported not only improvements in ecological literacy but also increased environmental awareness and pro-environmental behavioral intentions (Hurrell et al., 2024; Sahabuddin et al., 2024).

2. AR and VR for Improving Learning Motivation and Engagement

Another important finding of this review concerns the positive influence of immersive technologies on learners' motivation and engagement. Environmental education frequently involves abstract concepts and complex environmental systems that may be difficult for learners to comprehend through conventional instructional approaches. The reviewed studies consistently reported that AR and VR increased learners' interest, curiosity, and active participation during environmental learning activities (Safitri et al., 2025; Chen et al., 2025).

The interactive features of AR and VR enable learners to engage directly with learning content rather than passively receiving information. This finding is consistent with Self-Determination Theory, which suggests that learning environments that support autonomy, competence, and engagement contribute positively to intrinsic motivation (Ryan & Deci, 2020). Through immersive simulations and interactive environmental scenarios, learners become more actively involved in the learning process and demonstrate greater enthusiasm for exploring environmental issues.

Similarly, Hajj-Hassan et al. (2024) reported that digital technologies can enhance sustainability education by increasing learner engagement and facilitating meaningful interactions with environmental content. The motivational benefits identified in this review suggest that AR and VR can contribute to more effective environmental education by promoting both cognitive and affective learning outcomes.

3. AR and VR for Promoting Pro-Environmental Behavior

One of the most significant findings emerging from this review is the ability of AR and VR to foster pro-environmental behavior. While environmental education traditionally focuses on increasing knowledge and awareness, immersive technologies provide opportunities to influence learners' emotions, attitudes, and behavioral intentions simultaneously. Several studies found that immersive experiences related to climate change, pollution, deforestation, and biodiversity loss increased environmental empathy and encouraged environmentally responsible actions (Hurrell et al., 2024; Mendoza et al., 2025).

The relationship between immersive experiences and behavioral change can be explained through environmental behavior theories, which emphasize that environmental knowledge alone is insufficient to produce behavioral transformation (Kollmuss & Agyeman, 2002). Emotional engagement, personal relevance, and direct experiences are also critical determinants of pro-environmental behavior. Virtual simulations allow learners to observe the consequences of environmental degradation from a first-person perspective, thereby creating stronger emotional connections to environmental issues.

The reviewed studies reported various forms of behavioral outcomes, including increased willingness to reduce plastic consumption, conserve energy, participate in recycling activities, support biodiversity conservation, and engage in environmental campaigns (Sahabuddin et al., 2024; Xiong et

al., 2024; Teh et al., 2025). These findings suggest that AR and VR can function not only as instructional tools but also as catalysts for environmental action and sustainable behavior.

4. Challenges and Future Directions

Despite the educational benefits identified in this review, several challenges continue to limit the widespread adoption of AR and VR in environmental education. The most commonly reported barriers include high implementation costs, limited technological infrastructure, inadequate internet connectivity, and unequal access to digital devices (Hajj-Hassan et al., 2024; Husamah et al., 2025).

Another significant challenge relates to educators' digital competencies. Effective integration of immersive technologies requires teachers to possess both technological and pedagogical knowledge. However, many educational institutions still face limitations in teacher training and technical support, reducing the effectiveness of AR and VR implementation in classroom settings.

Additionally, some studies reported usability concerns associated with prolonged VR use, including eye strain, dizziness, and motion sickness among certain learners (Ladykova et al., 2024). These challenges highlight the need for careful instructional design and appropriate technology selection when implementing immersive learning experiences.

Future research should focus on examining the long-term effects of AR and VR on ecological literacy and pro-environmental behavior across diverse educational contexts. Further investigations are also needed to explore the integration of immersive technologies with innovative pedagogical approaches such as project-based learning, inquiry-based learning, and Education for Sustainable Development (ESD). Such efforts may contribute to the development of more effective and sustainable environmental education practices.

Overall, the findings of this review demonstrate that AR and VR represent promising educational technologies for strengthening ecological literacy, increasing learner engagement, and fostering pro-environmental behavior. With adequate infrastructure, teacher preparation, and pedagogical support, immersive technologies can play a significant role in advancing environmental education and promoting sustainability-oriented learning.

CONCLUSION

This systematic literature review examined the role of Augmented Reality (AR) and Virtual Reality (VR) in enhancing ecological literacy and promoting pro-environmental behavior within environmental education. The findings indicate that both technologies provide significant educational benefits by creating interactive, immersive, and meaningful learning experiences. AR and VR facilitate the visualization of complex environmental concepts, improve learners' understanding of ecological systems, and strengthen ecological literacy across different educational levels.

The review also revealed that immersive technologies positively influence learners' motivation, engagement, and environmental awareness. Through virtual simulations and interactive learning environments, learners are able to experience environmental issues more directly, resulting in greater empathy toward environmental challenges and a stronger commitment to environmentally responsible actions. Furthermore, AR and VR contribute to the development of pro-environmental behavior by encouraging sustainable practices such as energy conservation, waste reduction, recycling, and participation in environmental protection activities.

Despite these advantages, several challenges remain in the implementation of AR and VR in environmental education, including limited technological infrastructure, high implementation costs, unequal access to digital devices, and the need for improved digital competencies among educators. Addressing these challenges is essential to maximize the educational potential of immersive technologies.

Overall, AR and VR represent promising educational tools for supporting environmental education and advancing sustainability goals. Future research should investigate the long-term impacts of immersive technologies on ecological literacy and pro-environmental behavior, as well as explore their integration with innovative pedagogical approaches and

diverse educational contexts. Such efforts may contribute to the development of more effective environmental education practices that foster environmentally responsible citizens and support sustainable development.

REFERENCES

Chen, B., Zhang, Y., & Li, H. (2025). Fostering learners' environmental literacy through augmented reality and virtual reality. Proceedings of the International Conference of the Learning Sciences, 2532–2534.

Ditrich, L., Corner, A., & Whitmarsh, L. (2025). A front-row seat to catastrophe: Testing the effect of immersive technologies on climate change learning and pro-environmental behavior intentions. Environmental Education Research. Advance online publication.

Hajj-Hassan, M., Al-Samarraie, H., & Eldenfria, A. (2024). Environmental education: A systematic review on the use of digital tools for fostering sustainability awareness. Sustainability, 16(9), 3733. https://doi.org/10.3390/su16093733

Hurrell, C., Brown, M., & Smith, J. (2024). Virtual reality facilitates pro-environmental behavioural intentions through climate change experiences. Environmental Education Research, 30(8), 1124–1142. https://doi.org/10.1080/13504622.2024.2342942

Husamah, H., Pantiwati, Y., & Sumarsono, P. (2025). Integration of digital technologies in environmental education: Opportunities and challenges for sustainable learning. Varidika, 37(1), 45–58.

Kollmuss, A., & Agyeman, J. (2002). Mind the gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? Environmental Education Research, 8(3), 239–260. https://doi.org/10.1080/13504620220145401

Koparan, B. (2025). Examining the impact of augmented reality texts on students' attitudes toward environmental issues and sustainable development. *Sustainability, 17*(13), 6172.

Ladykova, T. I., Ivanova, E. V., & Petrova, A. N. (2024). Augmented reality in environmental education: A systematic review. European Journal of Mathematics and Science Technology Education, 20(5), em2419.

Mendoza, K. R., Van der Meer, J., & Peters, R. (2025). A systematic literature review on the impact of extended reality on pro-environmental knowledge, attitudes, and behaviors. Computers & Education Open, 7, 100215.

Orr, D. W. (1992). Ecological literacy: Education and the transition to a postmodern world. State University of New York Press.

Öztürk, E. (2023). Can environmental education supported by augmented reality improve students' environmental knowledge, attitudes, and behaviors? Educational Policy Analysis and Strategic Research, 18(2), 112–128.

Ryan, R. M., & Deci, E. L. (2020). Intrinsic and extrinsic motivation from a self-determination theory perspective: Definitions, theory, practices, and future directions. Contemporary Educational Psychology, 61, 101860. https://doi.org/10.1016/j.cedpsych.2020.101860

Sahabuddin, E. S., Rahman, A., & Yusuf, M. (2024). Utilization of virtual reality as a learning tool to increase students' pro-environmental behavior at higher education level. European Journal of Mathematics and Science Technology Education, 20(8), em2457.

Safitri, D., Hidayat, T., & Prasetyo, A. (2025). Transforming environmental education with augmented reality: Enhancing environmental awareness and learning outcomes. Heliyon, 11(4), e42015.

Simon, P. D., Zhong, Y., Dela Cruz, I. C., & Fryer, L. K. (2025). Scoping review of research on augmented reality in environmental education. *Journal of Science Education and Technology, 34*(4), 919–935. https://doi.org/10.1007/s10956-025-10218-z

Teh, C., Lim, K. S., & Abdullah, N. (2025). Eliciting pro-environmental behavior with

immersive technologies: A review of recent evidence. Energy Research & Social Science, 122, 103997.

Xiong, S. R., Liu, Y., & Wang, H. (2024). Virtual environment, real impacts: A self-determination theory perspective on virtual reality and pro-environmental behavior. Local Environment, 29(7), 765–781. https://doi.org/10.1080/13549839.2024.2361270

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