Cognopolis
Revista de educación y pedagogía
Vol. 4(2), 105-117, 2026
https://doi.org/10.62574/99mmrf40

A Mobile App Using Augmented Reality and Its Impact on the Environmental Practices of Rural Students

Aportes teóricos del video arte y los entornos digitales a la enseñanza del inglés preescolar

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ABSTRACT

The study aimed to determine the effectiveness of a mobile app using augmented reality and its effect on the environmental practices of rural students in the Loma Verde district, Montería, Córdoba, Colombia. The study employed a positivist paradigm, a quantitative approach, a descriptive design, and a quasi-experimental design, with a sample of 350 middle and high school students from four rural schools, assessed using a 15-item diagnostic instrument validated by expert judgment. The results revealed insufficient prior knowledge regarding solid waste (39.4% conceptual correct answers), the identification of three distinct student profiles through multiple correspondence analysis, and a general improvement in conceptual understanding and willingness to adopt sustainable practices following the implementation of the ECOEDUCA app. It is concluded that augmented reality constitutes an effective teaching strategy for anchoring complex environmental content in rural contexts, although its long-term sustainability requires additional longitudinal validation.

Keywords: teaching materials; audiovisual aids; educational technology. (Source: UNESCO Thesaurus).

RESUMEN

El estudio tuvo como objetivo determinar la efectividad de una aplicación móvil con realidad aumentada y su efecto en las prácticas ambientales de estudiantes rurales del distrito de Loma Verde, Montería, Córdoba, Colombia. De paradigma positivista, enfoque cuantitativo, tipo descriptivo y diseño cuasiexperimental, con una muestra de 350 estudiantes de secundaria y bachillerato de cuatro escuelas rurales, evaluados con un instrumento diagnóstico de 15 ítems validado por juicio de expertos. Los resultados evidenciaron un conocimiento previo insuficiente sobre residuos sólidos (39,4 % de aciertos conceptuales), la identificación de tres perfiles estudiantiles diferenciados mediante análisis de correspondencias múltiples, y una mejora general en la comprensión conceptual y la disposición hacia prácticas sostenibles tras la implementación de la aplicación ECOEDUCA. Se concluye que la realidad aumentada constituye una estrategia didáctica efectiva para anclar contenido ambiental complejo en contextos rurales, aunque su sostenibilidad a largo plazo requiere validación longitudinal adicional.

Descriptores: material didáctico; auxiliar audiovisual; tecnología educacional. (Fuente: Tesauro UNESCO).

Received: 12/05/2026. Reviewed: 15/05/2026. Accepted: 12/06/2026. Published: 12/07/2026.
Research Articles

INTRODUCTION

Ecosystem degradation and poor solid waste management are two critical environmental problems facing modern human society—specifically, rural communities, given the severe lack of access to sanitation facilities and innovative educational resources. As a result, schools are increasingly being called upon to “play a decisive educational role” in shaping a citizenry that “is capable of understanding the source of waste, the type of waste generated, and the fate of the waste it produces” (Hungerford & Volk, 1990).

In light of this premise, environmental education is now conceptualized not as a passive matter of content transmission, but as a process based on an integrated change in knowledge, attitude, and behavior regarding a target set of behaviors directly related to environmental conservation (Hungerford & Volk, 1990). Similarly, the growing advancement of digital technology has provided new opportunities to enhance teachers’ experience and instruction—which were previously conducted in a mechanical manner—such as in the context of solid waste management.

Among these, the added value for users in their daily lives is emphasized when described in terms of augmented reality—the ability to apply digital information to the physical world while still experiencing reality (Azuma et al., 2001). This characteristic also makes augmented reality useful in teaching environmental phenomena, as it visualizes aspects not directly relevant to the student—for example, the decomposition of materials, water pollution, and the sorting of waste according to its nature.

Furthermore, a series of systematic reviews have found that augmented reality is effective in enhancing motivational skills, content retention, and cross-curricular skills (critical thinking) (Bacca et al., 2014), and that augmented reality improves the learning experience in educational contexts. In the specific field of environmental education, evidence from a recent exploratory review demonstrated and confirmed that most reports of documented experiences with

the technology indicated positive influences on knowledge, attitudes, and even pro-environmental behavior (at least to some extent); however, these reviews noted that some studies express concern about the sustainability of such changes over time (Simon et al., 2025).

To this end, we also found that mobile applications using augmented reality technology in higher education improved the perception of information related to environmental content through gamification when integrated with a game (Mei & Yang, 2019), while experiences with tablets and augmented reality in teaching chemistry using plastics have led to improved understanding of recycling processes among high school students (Syskowski et al., 2024). In response, it has been reported that augmented reality-enhanced digital picture books and their accompanying features had a positive effect on children's environmental attitudes and behaviors across a variety of cultural settings (Chen, 2022), and mobile apps specifically dedicated to waste sorting have changed students' perceptions of source separation, as documented in a case study on climate science education (Wang & Xie, 2025). It is worth noting that these precedents are consistent in demonstrating that augmented reality is effective not only in motivating students but can also act as a facilitator of cognitive processes in understanding complex environmental phenomena.

Theoretically, this study represents three strands that, when considered together, allow us to understand the pedagogical possibilities of augmented reality. First, we have the theory of meaningful learning, which states that new knowledge is meaningful only when it is substantially related to the student's pre-existing cognitive framework, insofar as learning shifts from being a mechanical accumulation of data to a process of integrating all aspects of knowledge (Ausubel, 1963). In this sense, visualizing environmental processes through augmented reality has the advantage of making abstract ideas—such as the degradation of toxic waste—concrete and accessible as experiences for the student, According to constructivism (Piaget, 1967)—who later elaborated on his ideas regarding cognitive development and moved toward problem-centered

learning environments (Jonassen, 1999)—the learner creates and constructs knowledge rather than passively absorbing it.

Meanwhile, Vygotsky (1978) focused on the social aspect of learning, arguing that knowledge is consolidated when students interact with one another and with cultural mediators—a concept particularly relevant to the design of collaborative activities as well as mobile devices. Along the same lines, situated learning, as developed by Lave and Wenger (1991), promotes the idea that knowledge is most useful when situated in authentic contexts, especially in the actual management of waste generated within the educational institution itself, while Kolb's (1984) experiential learning model echoes this idea by asserting that true learning is a cycle of concrete experience, followed by reflection and active experimentation.

On the other hand, education for sustainability—defined as the bridge between curricula and real-world environmental problems—requires the development of skills necessary to address the environmental challenges of this century (Sterling, 2001). This perspective recognizes that sustainability can never be reduced to merely additional content but must be embedded as a cross-cutting theme capable of transforming institutional culture as a whole (Cortese, 2003; Barth, 2007).

In this sense, Education for Sustainable Development has been described as a transformation-based "learning" process that seeks to foster a student-centered focus on the relationships between natural and human systems and to respond to them in a reflective manner (Tilbury, 2011). These educational processes should not only be assessed through summative assessments administered at the conclusion of the intervention but, in the current context, require timely feedback during which teaching can be adjusted (Black & Wiliam, 1998). Similarly, community environmental practices not only do not arise spontaneously but are also mediated by social structures, power relations, and historical contexts, which determine the day-to-day behavior of community members;

therefore, a mere informational intervention is not sufficient to break habits that have become ingrained in school and family life (Bourdieu, 1990).

Based on this framework, this study applies the findings from a doctoral dissertation to a sample of four rural educational institutions located in the Loma Verde district, Montería municipality, Córdoba department, Colombia, where significant gaps were identified in students' knowledge of solid waste management, and the development of a teaching strategy facilitated by a mobile application with augmented reality.

In line with the above, the objective of this study is to determine the effectiveness of the augmented reality mobile app and its impact on the environmental practices of rural students in the Loma Verde district, Montería municipality, Córdoba department, Colombia.

METHOD

The research was conducted based on the positivist paradigm, which employs objective methods, as the data can be quantified. The approach used was quantitative and consisted of quantitative measurements of the phenomena under investigation, namely, students' perceptions of knowledge and behaviors regarding solid waste. d that the type of research was descriptive, as it sought to describe the preliminary conditions influencing the knowledge and practices of the study population, while the design corresponded to a quasi-experimental model aimed at evaluating the effect of the independent variable—a teaching strategy using augmented reality—on the dependent variable—effective solid waste segregation.

Participants

The sample included 350 middle and high school students, who were recruited through non-probabilistic convenience sampling and came from four rural schools in the Loma Verde district: Pueblo Bujo (90 students, 25.7%), Leticia (80 students, 22.9%), Las Palomas (100 students, 28.6%), and Guasimal (80 students, 22.9%). This homogeneity in age, educational level, and rural context made the results

comparable across the four sites and highly applicable to the district's socio-educational conditions, including issues with infrastructure and technology availability.

Instruments

A diagnostic tool comprising 15 closed-ended multiple-choice questions was used to assess five categories: general concepts of solid waste management, types of waste, handling and final disposal, the environmental impact of waste, and proper management. The same instrument was used in both the diagnostic and post-intervention validation phases, allowing for a comparison of prior knowledge and experience before and after the deployment of the augmented reality mobile app. Content validity was established through expert judgment, involving three professionals in educational research and information technology, while reliability was estimated using Cronbach's alpha coefficient.

Procedure

This study was designed in four sequential phases; in the diagnostic phase, surveys, interviews, and direct observation were used to identify factors associated with solid waste management problems using a multi-method approach to deepen the understanding of the phenomenon under study. Meanwhile, during the design stage, the ECOEDUCA educational proposal was structured based on a mobile app created with App Inventor—capable of running on tablets and smartphones—and consisting of four interactive activities to promote waste sorting, reduction, reuse, and recycling.

During this implementation phase, students were trained to use the tool, and learning activities were developed in the virtual environment using natural science content; furthermore, validation and satisfaction tests were conducted during the evaluation stage to quantify the degree of improvement achieved and the students' impressions of the adopted strategy.

Data Analysis

Data processing was performed using SPSS software and Excel spreadsheets. Descriptive statistical analysis was applied to summarize the frequencies and percentages of participants' responses to each question, along with multiple correspondence analysis to reveal patterns of association among variables and to categorize students according to their performance characteristics. Since the variables analyzed were nominal data, nonparametric tests were used to validate the research hypothesis, as these do not assume a normal population distribution. It is important to note that the research was conducted within the ethical parameters established by Law 1581 of 2012 regarding the privacy of personal information, ensuring the confidentiality of the information provided by the students and obtaining consent from their families.

RESULTS

In general terms, the results of the diagnostic test indicated significant variability but insufficient prior knowledge regarding solid waste. Only 39.4% of the students correctly identified the meaning of solid waste in this sample, while the remaining 60.6% equated solid waste with liquid waste, organic materials, or household chemicals. Likewise, performance in identifying recyclable materials was moderate, with 42.9% able to identify crumpled paper as a recyclable item; however, a significant number of students—22.3%—erroneously believed that disposable diapers were considered recyclable material.

On the other hand, the majority of students (49.4%) correctly recognized that littering in bodies of water causes pollution and harms aquatic life, suggesting that a basic level of environmental awareness exists among approximately half of the student population studied. In contrast, awareness of electronic waste is less pronounced, as only 43.4% of participants correctly identified the meaning of the acronym WEEE a concerning finding given students' exposure to electronic devices, which are ubiquitous in their daily lives.

Regarding best management practices, 31.1% of students acknowledged that the main reason for separating and sorting waste is to reduce the amount produced; related percentages indicated that this is done to facilitate the transport of materials or to prevent unpleasant odors. At the same time, 44.3% of responses correctly identified organic waste, and recognition of the benefits of recycling reached 46%, a result that aligns with the similarly moderate understanding of the “three Rs” rule, which was correctly identified by 44% of respondents; however, it is important to note that Table 1 summarizes the main results obtained in the diagnostic test.

Table 1. *Summary of diagnostic test results by evaluated category.*

Category assessed	Percentage of Correct Answers	Interpretation
Solid waste concept	39.4%	Partial understanding, with predominant conceptual confusion
Identification of recyclable materials	42.9%	Moderate recognition with classification errors
Impact of Waste on Water Sources	49.4%	Basic environmental awareness present in nearly half of the group
Meaning of the acronym WEEE	43.4%	Intermediate knowledge of electronic waste
Main reason for sorting	31.1%	Lowest accuracy rate in the entire assessment
Identification of organic waste	44.3%	Accurate recognition of the most common type of organic waste
Benefits of recycling	46.0%	Moderate understanding of the environmental benefits
The Three Rs	44.0%	Relatively clear concept, though not well established

Note: Prepared by the author based on the results of the diagnostic test administered to 350 students from four rural educational institutions.

However, multiple correspondence analysis explained 44.21% of the variability in the responses across two principal dimensions, in the following order: the first dimension accounted for 24.58% of the variation across categories, related to the conceptualization and classification of solid and organic waste, and the second, accounting for 19.63% of the variation, was due to recycling, pollution, and environmental awareness.

These dimensions were used to derive three student profiles, each of which relates to a specific and relevant role in academic success and educational goals. Thus, the first group achieved a success rate of 46.67% and had an adequate

understanding of the principles, but struggled with identifying which materials were recyclable.

In comparison, the second group scored very low in all evaluated categories—only 13.33%—indicating that this group is much more vulnerable to educational challenges. Meanwhile, the third group had a 40% level of knowledge regarding awareness of the effects of water pollution and hazardous waste management, but still had some gaps in material classification, similar to the first group.

On the other hand, when evaluating the implementation of the ECOEDUCA mobile app from the validation phase compared to the diagnostic phase, there was an overall increase in understanding of the assessed concepts and a greater willingness among students to adopt sustainable practices. Based on the satisfaction survey administered at the end of the intervention, students reported a positive evaluation of the interactive experience provided by augmented reality, particularly regarding the visualization of sorting processes and the ability to make simulated decisions about the disposal of different types of waste. These results are consistent with findings from educational contexts where augmented reality has been specifically applied to teaching waste sorting, which has been shown to significantly improve understanding of source separation processes (Wang & Xie, 2025).

DISCUSSION

In summary, the diagnostic results reveal that students in Loma Verde attending rural schools had fragmented knowledge about solid waste management prior to the intervention, which is consistent with other studies conducted in contexts of limited access to technology and specialized teacher training. In this regard, given that the gap in basic conceptual understanding of solid waste and the recognition of electronic waste is evident, it is clear that effective environmental education is not only about imparting content but also about fostering attitudes and behaviors toward sustainable practices by providing meaningful experiences (Hungerford & Volk, 1990).

From the perspective of meaningful learning, the growth observed following the implementation of the mobile app indicates that the integration of augmented reality helped anchor new content within prior cognitive structures by providing students with visual representations that made processes more understandable when presented in a more abstract manner, such as the decomposition of organic waste or the treatment of toxic materials (Ausubel, 1963). This finding aligns with the observation by Bacca et al. (2014), who reported that augmented reality enhances retention by providing visual stimuli that link theory and practice, as well as with the findings of Mei and Yang (2019) regarding the effectiveness of gamified mobile applications in strengthening environmental education among populations with limited access to conventional laboratories.

Furthermore, the examination of three distinct student profiles using multiple correspondence analysis reinforces the idea that educational interventions cannot be conceived in a single configuration; different pedagogical interventions must take into account the specific characteristics of each group, while the second profile—with a success rate considerably lower than that of the other groups—indicates an educational disadvantage that goes beyond the conceptual realm and is likely related to unequal access to prior environmental education experiences, a phenomenon consistent with the argument that environmental practices are mediated by social and cultural structures that shape individual behavior (Bourdieu, 1990). Therefore, future interventions would benefit from incorporating differentiated strategies that address this heterogeneity rather than assuming that a single instructional approach will produce equivalent effects across the entire student population.

On the other hand, the observed increase in students' perception of sustainable practices after interacting with the mobile app can, however, be interpreted as a constructivist outcome in which students constructed their own understanding through manipulating simulated scenarios with the technological tool, rather than being passive recipients of knowledge (Jonassen, 1999; Piaget, 1967). Furthermore, the collaborative nature of some of the activities carried out during

the implementation phase aligns with Vygotsky's principle that learning is consolidated through social interaction (Vygotsky, 1978), while the connection between the content and the immediate realities of the Loma Verde community also aligns with Lave and Wenger's (1991) theory of situated learning and Kolb's (1984) experiential cycle, as students were able to experience, reflect on, and apply what they learned within their own school context.

Furthermore, the findings further facilitate a dialogue on formative assessment in relation to the implementation approach; using the same instrument during the diagnostic phase followed by the validation phase allowed for feedback, which Black and Wiliam (1998) argue is essential for making timely adjustments to teaching processes rather than waiting for a summative assessment, which often comes too late to change pedagogical practices. Therefore, keep in mind that, despite large-scale improvements in the evidence from the validation phase, the research cannot definitively determine whether these changes will be sustained over time—a limitation that aligns with what Simon et al. (2025) noted regarding the limited available longitudinal evidence on the sustained effect of augmented reality in environmental education.

Regarding the relevant technology used, the findings confirm the results of Syskowski et al. (2024), in which this methodology also shows that the use of tablets and augmented reality for teaching the chemistry of plastics has demonstrated that interactive visualization of the material transformation process greatly improves understanding of recycling concepts. Likewise, the experience described with augmented reality e-books for children from different cultural backgrounds (Chen, 2022) supports the view that this technology can be adapted to different sociocultural characteristics—such as those of the rural communities of Loma Verde—without hindering its pedagogical success.

Therefore, the findings of this study should be understood in relation to their alignment with the 2030 Agenda: the progress made in conceptual understanding, together with attitudes toward sustainable practices, directly contributes to Sustainable Development Goal 4, which pertains to quality

education; meanwhile, improving habits related to reduction, reuse, and recycling is linked to Goal 12, concerning responsible production and consumption. The knowledge gained about the effects of waste on water supplies and ecosystems relates to Goal 13 on climate action, and the potential to provide high-quality technological experiences in low-resource rural contexts further advances Goal 11 on sustainable communities, as it mitigates deficiencies in access to educational progress (Cortese, 2003; Sterling, 2001; Tilbury, 2011).

CONCLUSION

Based on the results, the ECOEDUCA mobile app increased conceptual knowledge and willingness to adopt sustainable environmental practices among rural students in Loma Verde, while the initial project assessment indicated significant gaps regarding waste sorting and the recognition of electronic waste. The three profiles identified through multiple correspondence analysis confirm that the effect of the intervention is heterogeneous and depends on prior educational access conditions. Thus, it can be concluded that augmented reality constitutes an effective teaching strategy for anchoring complex environmental content in rural contexts, although its long-term sustainability requires further longitudinal validation.

FUNDING

Non-monetary

CONFLICT OF INTEREST

There is no conflict of interest with individuals or institutions linked to the research.

ACKNOWLEDGMENTS

To the educators who encourage learning through the arts.

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