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Immersive Digital Technologies in Early Childhood Education: Advancing Environmental Awareness and Sustainability

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Introduction

In the digital era, rapid technological advancements have transformed nearly every facet of society, and education is no exception. The integration of digital tools has shifted traditional pedagogical models toward more dynamic, interactive, and student-centered approaches. Among these digital innovations, Virtual Reality (VR) and Augmented Reality (AR) have emerged as transformative technologies capable of creating immersive learning environments that significantly enhance the educational experience (Kim & Lee, 2021; Smith et al., 2022). Simultaneously, global challenges such as climate change, resource depletion, and environmental degradation have underscored the critical need to incorporate sustainability into educational curricula. As a result, there is a growing impetus to blend digital technology with sustainable environmental education, especially during early childhood—a formative period when attitudes and behaviours are first shaped.

Recent studies have documented the potential of VR and AR in revolutionizing education by offering learners interactive simulations that foster deeper understanding and engagement. VR enables users to experience entirely simulated environments, allowing them to explore complex and abstract concepts in a controlled, risk-free setting (Martin, 2018). For example, virtual field trips to endangered ecosystems or simulated environments that depict the consequences of environmental mismanagement can provide tangible experiences that are otherwise difficult to replicate in a traditional classroom. AR, on the other hand, overlays digital information onto the real world, enriching everyday environments with interactive elements that stimulate curiosity and learning (Lee et al., 2021). These immersive technologies not only enhance cognitive engagement but also promote the development of critical thinking and problem-solving skills by actively involving students in the learning process (Wang et al., 2020).

Early childhood, defined in this study as the period between ages 5 and 8, is a critical window for cognitive, social, and emotional development. Educational experiences during these formative years have long-lasting effects on a child's academic trajectory and worldview. Research suggests that integrating digital technologies in early education can lead to improved learning outcomes, heightened motivation, and enhanced social interactions (Johnson, 2019). However, while the benefits of VR and AR have been explored extensively in secondary and tertiary education settings, their application within early childhood education—particularly in fostering environmental awareness—remains relatively underexplored. This gap is significant because early exposure to sustainability concepts can lay the foundation for lifelong environmental stewardship.

The integration of sustainability into education is a priority underscored by international policy frameworks such as the United Nations Sustainable Development Goals (SDGs). Specifically, SDG 4 emphasizes the importance of quality education, while SDG 13 calls for urgent action to combat climate change and its impacts (UNESCO, 2021). Embedding sustainability into early learning not only equips children with essential academic skills but also cultivates an awareness of environmental issues and encourages responsible behaviour toward nature. Early environmental education has been shown to foster a sense of stewardship and a proactive approach to environmental challenges, which are crucial for the sustainable development of communities (Davis & Green, 2020). In this context, VR and AR offer innovative avenues to engage young learners with sustainability issues through experiential learning.

Despite the promising prospects, there is a notable paucity of empirical research that investigates the integration of VR and AR within early childhood education for the explicit purpose of promoting environmental awareness. Most studies to date have concentrated on older students or have focused solely on academic performance without

addressing the potential for fostering sustainable practices (Brown et al., 2021). Given that early childhood is a period when foundational attitudes toward the environment are formed, it is essential to explore how immersive digital experiences might contribute to a more sustainable mindset among young learners. Moreover, the dynamic nature of digital technologies calls for continuous evaluation of their pedagogical implications to ensure that their use aligns with evolving educational and environmental objectives (Kim & Lee, 2021).

The present study seeks to address these gaps by exploring how VR and AR technologies can be integrated into early childhood education to enhance both academic learning and environmental awareness. By employing an experimental design that includes direct observations and semi-structured interviews with teachers and parents, the study aims to assess the impact of these digital tools on the development of critical thinking, problem-solving, and environmental consciousness among children aged 5 to 8 years. A comparative analysis between children exposed to VR and AR-enhanced learning environments and those engaged in traditional learning methods will provide insights into the effectiveness of immersive technologies in early education.

This study is significant for several reasons. First, it contributes to the growing body of literature on digital education by extending the focus of VR and AR applications to early childhood—a critical period for cognitive and social development. Second, it aligns with global sustainability initiatives by investigating how technology can be leveraged to foster early environmental awareness, thereby supporting the goals of sustainable development. Finally, the findings of this study have practical implications for policymakers and educators, as they provide evidence-based recommendations for integrating digital technology into early childhood curricula. Such integration not only enhances the quality of education but also prepares the next generation to address pressing environmental challenges.

In the sections that follow, the study will outline the experimental methodology specifically designed to address the problem and answer the study questions. It will present comparative analyses between immersive digital learning experiences facilitated by VR and AR and those provided by traditional educational methods. Furthermore, the study will discuss the broader implications of its findings for educational practices and policy development. By integrating digital innovation with sustainable education, this study aspires to pave the way for a generation of young learners who are more engaged, environmentally conscious, and technologically proficient.

Objectives of the Study

The main objective of this study is to investigate the impact of immersive digital technologies—specifically Virtual Reality (VR) and Augmented Reality (AR)—on enhancing environmental awareness and promoting sustainable behaviors among children aged 5 to 8 in Jeddah, Saudi Arabia.

In line with this aim, the study pursues the following specific objectives:

To evaluate the extent to which VR and AR applications improve children’s environmental knowledge, attitudes, and sustainable practices compared to traditional teaching methods.

To explore the perceptions of teachers and parents regarding the effectiveness, challenges, and opportunities of integrating VR and AR into early childhood education.

To provide evidence-based recommendations for the design of age-appropriate immersive digital learning environments that support both academic development and environmental awareness.

1. Significance of the Study

This study holds both theoretical and practical significance.

3.1 Theoretical Significance

This study advances the scholarly discourse on immersive digital technologies in early childhood education by addressing a critical research gap. Although the pedagogical value of Virtual Reality (VR) and Augmented Reality

(AR) has been extensively investigated in secondary and higher education, their application in early childhood settings—particularly in cultivating environmental awareness—remains underexplored. By focusing on children aged 5 to 8, this research extends current theoretical frameworks of sustainability education to a formative developmental stage, providing evidence that immersive experiences can transform abstract ecological concepts into concrete understanding.

3.2 Practical Significance

The findings also yield practical implications for stakeholders directly engaged in early education and sustainability initiatives. For educators and curriculum developers, the study offers guidance on how VR and AR can be integrated into age-appropriate learning environments to foster pro-environmental knowledge, attitudes, and behaviours. For policymakers, the results provide empirical justification for incorporating immersive technologies into national education and climate strategies. By linking these outcomes to the United Nations Sustainable Development Goals—specifically SDG 4 (Quality Education) and SDG 13 (Climate Action)—the study demonstrates its broader relevance to global sustainability agendas.

2. Definition of Key Terms

For this study, the following key terms are defined both conceptually, based on recent literature, and operationally, as applied in this research:

Virtual Reality (VR): Conceptually, VR refers to a computer-generated, three-dimensional environment that allows users to explore and interact with simulated settings through head-mounted displays, motion tracking, and sensory feedback systems (Kim & Lee, 2021; Marougkas et al., 2023). It provides fully immersive experiences that replicate or model real-world phenomena, enabling learners to engage with abstract or inaccessible contexts in a tangible way. Operationally, in this study, VR denotes the use of age-appropriate immersive simulations specifically developed to expose children aged 5 to 8 to environmental scenarios. These simulations included interactive experiences of endangered ecosystems, deforestation, and climate change impacts. The operationalization of VR was measured through children's engagement with the simulations during classroom sessions, as well as through subsequent changes in their environmental awareness scores on the Environmental Awareness Assessment Tool.

Augmented Reality (AR): Conceptually, AR refers to the integration of computer-generated objects, images, or information into real-world environments, enriching everyday experiences with interactive digital elements (Lee et al., 2021). Unlike VR, which creates fully simulated worlds, AR overlays digital content on physical surroundings, fostering multisensory engagement and enhancing learners' curiosity and interaction with real contexts. Operationally, in this study, AR denotes the use of classroom-based applications that embed environmental content into children's physical learning activities. Examples included interactive overlays of endangered species, pollution sources, and conservation practices within familiar classroom settings. Its operationalization was reflected in how children engaged with these overlays and in their subsequent improvement in environmental awareness scores, as captured by the Environmental Awareness Assessment Tool.

Early Childhood (5–8 years): Conceptually, early childhood is defined by UNICEF (2019) and UNESCO (2021) as the developmental period from birth to eight years, encompassing rapid growth in cognitive, social, and emotional domains. It is widely recognized as a formative stage in which foundational skills, attitudes, and behaviours are shaped. Operationally, in this study, early childhood refers specifically to children aged 5 to 8, representing the transitional phase from preschool to early primary education. This age range was selected because it marks a critical period in which cognitive, social, and environmental attitudes begin to consolidate, making it particularly suitable for examining the impact of immersive digital technologies on environmental awareness.

Environmental Awareness: Conceptually, environmental awareness is understood as a multidimensional construct encompassing knowledge, attitudes, and behaviors toward sustainability and responsible interaction with natural resources (Davis & Green, 2020). It implies both cognitive recognition of environmental issues and the affective-motivational drive to act responsibly. Operationally, in this study, environmental awareness was defined as children

demonstrated understanding, attitudes, and behaviors related to environmental care. It was measured through a structured Environmental Awareness Assessment Tool tailored for ages 5 to 8, which assessed recognition of environmental issues (e.g., recycling, conservation), attitudes toward sustainability, and observable pro-environmental behaviors.

3. Problem Statement and Study Questions

5.1 Problem Statement

Early childhood education, specifically for children aged 5 to 8, plays a crucial role in shaping foundational cognitive, social, and environmental attitudes. Despite the rapid advancement of digital technologies, particularly Virtual Reality (VR) and Augmented Reality (AR), their integration into early childhood education remains notably underexplored. While these immersive tools have shown promise in enhancing learning outcomes in secondary and tertiary settings, traditional teaching methods continue to dominate early educational environments. This limits opportunities for young learners to engage with innovative approaches that could foster both academic excellence and a heightened awareness of environmental sustainability.

Given the intensifying global challenges such as climate change and environmental degradation, it is imperative to equip children in this critical age group with the skills and consciousness necessary for future stewardship of the environment. However, the lack of empirical evidence on the effectiveness of immersive digital experiences in early childhood settings poses a significant challenge for educators and policymakers. There is a pressing need to understand how VR and AR technologies can be harnessed to improve academic performance while simultaneously nurturing environmental awareness among early childhood learners.

3.2 Study Questions

To address the above problem, this study is guided by the following main question and its sub-questions:

Main Study Question:
How does the integration of VR and AR technologies in early childhood education aged (5 to 8) affect the development of environmental awareness compared to traditional teaching methods?

Sub-Questions:

1_How do immersive digital experiences provided by VR and AR influence the development of environmental awareness and responsible behaviour toward sustainability in early childhood learners?

2_What are the perceptions of teachers and parents regarding the effectiveness, challenges, and opportunities associated with integrating VR and AR technologies in early childhood education?

4. Theoretical Framework

The rapid advancement of digital technologies has transformed various aspects of education, prompting a shift toward more immersive and interactive learning environments. In recent years, the emergence of tools such as Virtual Reality (VR) and Augmented Reality (AR) has generated considerable interest in their application in early childhood education. This study focuses on children aged 5 to 8, a critical developmental period, to explore how immersive digital experiences can foster academic learning and enhance environmental awareness. Given global challenges such as climate change and environmental degradation, integrating sustainability into early education is increasingly imperative. This section outlines the theoretical framework that informs the study, reviews recent literature on digital technology in early childhood education and sustainable learning and identifies gaps in previous studies that this study aims to address.

The theoretical framework guiding this study draws upon several interrelated theories that explain how digital technologies can enhance learning and promote sustainable behavior. These include constructivist learning theories, experiential learning theory, and theories related to environmental education.

Constructivist theories posit that learners actively construct knowledge through their interactions with the world (Piaget, 1972; Vygotsky, 1978). In the context of digital learning, constructivism suggests that immersive environments—such as those offered by VR and AR—can facilitate deeper learning by enabling children to explore, experiment, and reflect on their experiences. Recent studies have reinforced the idea that digital tools promote active engagement and provide opportunities for learners to build their own understanding of complex subjects (Kim & Lee, 2021). For early childhood learners who are naturally curious and exploratory, constructivist approaches can be especially effective in bridging abstract concepts with tangible experiences (Abdulkareem, 2023).

Experiential learning theory, as advanced by Kolb (1984), emphasizes learning through experience, reflection, and application. This theory is particularly relevant to the use of VR and AR in educational settings because these technologies offer immersive simulations that mimic real-world scenarios. Experiential learning posits that when children are provided with hands-on opportunities to engage in simulated environments, they not only acquire factual knowledge but also develop critical thinking and problem-solving skills (Wang et al., 2020). In the context of environmental education, experiential learning allows children to virtually explore ecosystems, witness the effects of environmental degradation, and consider sustainable practices in a safe, controlled setting (Davis & Green, 2020).

Environmental education aims to increase awareness and understanding of environmental issues, fostering attitudes and behaviors that promote sustainability. According to the United Nations Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education) and SDG 13 (Climate Action), integrating environmental education into all levels of schooling is crucial for cultivating responsible citizenship (UNESCO, 2021). The theoretical underpinning of environmental education is grounded in the idea that early exposure to sustainability concepts can shape long-term attitudes toward the environment (Brown et al., 2021). By combining digital technologies with environmental education, educators can create immersive learning experiences that not only convey knowledge but also inspire behavioral change toward sustainability.

6.1 Literature Review

This literature review examines recent studies on the use of digital technology in early childhood education, the application of VR and AR in teaching and learning, and the integration of sustainability into educational practices. Emphasis is placed on research published within the last seven years to ensure the relevance and currency of the evidence.

Digital technology has been widely acknowledged as a transformative force in education. Johnson (2019) found that the integration of digital tools in early childhood settings can improve engagement and enhance learning outcomes by providing interactive and personalized learning experiences. According to recent studies, digital tools not only improve academic performance but also support the development of social skills and critical thinking (Smith et al., 2022). However, much of the existing literature has focused on older students or has generalized findings across different age groups, with limited attention given specifically to the 5-8 age range. This gap is critical, as early childhood represents a formative period where foundational cognitive and environmental attitudes are established.

In a qualitative study conducted by Abdulkareem (2023) investigating the role of virtual reality (VR) in early childhood development among children aged four to six, the results revealed that VR exerts a dual-edged influence on developmental outcomes. The study documented that VR contributes positively across several developmental domains, notably enhancing cognitive functions and academic skills while bolstering self-awareness, self-confidence, and empathy. Notable improvements were observed in children's emotional and behavioural self-regulation, including increased attention control, enhanced working memory, improved impulse inhibition, greater patience, and more effective task completion.

Conversely, the study also identified a range of adverse effects, such as potential physiological health risks, the emergence of false memories, and a propensity for addictive behaviour. Additional challenges included exposure to inappropriate content, social isolation, difficulties in regulating emotional expression, and an increased tendency toward aggressive behaviour. These findings underscore the critical importance of adult supervision and highlight the need for developing age-appropriate, high-quality VR content to maximize developmental benefits while mitigating potential risks.

The application of VR and AR in education has garnered substantial attention due to its potential to create immersive, interactive learning environments. Martin (2018) highlighted that VR provides learners with the opportunity to experience simulated environments that are otherwise inaccessible in traditional classrooms. For example, virtual field trips can transport children to remote ecosystems, offering experiential insights into environmental issues. Similarly, AR overlays digital content onto the physical world, enhancing real-life observations with interactive information (Lee et al., 2021).

Kim and Lee (2021) conducted a systematic review of AR and VR in education and reported that these technologies significantly enhance student engagement and motivation. The review emphasized that immersive digital experiences foster deeper understanding by allowing learners to visualize and interact with complex concepts. Moreover, Wang et al. (2020) demonstrated that such experiences contribute to the development of critical thinking and problem-solving skills—capabilities that are essential for addressing environmental challenges.

Despite these promising findings, most studies have focused on the use of VR and AR in secondary and tertiary education. The application of these tools in early childhood education, particularly for the purpose of promoting environmental awareness, remains underexplored. This study addresses this gap by focusing on children aged 5 to 8 and assessing the impact of immersive digital technologies on both academic performance and environmental consciousness.

Integrating sustainability into education has emerged as a global priority, driven by the urgency to address climate change and environmental degradation. UNESCO (2021) and various national education frameworks advocate for the inclusion of sustainability principles in school curricula. Davis and Green (2020) have shown that early environmental education not only improves ecological literacy but also instils a sense of responsibility and stewardship toward the environment. Their work underscores the importance of embedding environmental education in early learning to ensure that sustainable practices become part of lifelong behaviour.

Recent studies have begun to explore the role of digital technology in environmental education. Brown et al. (2021) argued that immersive technologies can effectively simulate environmental scenarios that help children understand the impact of human activities on nature. Such simulations offer a unique way to communicate the complexities of environmental issues in a manner that is accessible and engaging for young learners. This aligns with the broader educational goal of creating learning environments that are both informative and transformative.

The intersection of digital technology and sustainable education represents a novel and promising area of inquiry. Theoretical perspectives suggest that when digital tools are used to create immersive learning experiences, they have the potential to simultaneously enhance academic learning and foster environmental awareness. For instance, VR-based simulations of deforestation, pollution, and climate change can provide concrete, experiential insights into abstract environmental issues. Such approaches not only convey scientific facts but also help children develop empathy and a proactive stance toward sustainability (Smith et al., 2022).

Lee et al. (2021) have emphasized that the integration of AR and VR in education supports a multisensory learning experience. This multisensory approach is particularly effective in early childhood education, where learning is enhanced through visual, auditory, and kinaesthetic engagement. By combining digital immersion with interactive learning, educators can create environments where sustainability is not only taught but also experienced. The convergence of these domains supports the development of a generation that is well-equipped to address future environmental challenges, both intellectually and behaviourally.

Several studies have provided preliminary evidence of the benefits of integrating digital technologies into sustainable education. For example, a study by Brown et al. (2021) demonstrated that children exposed to VR-based environmental simulations showed a marked increase in environmental awareness and a greater inclination toward eco-friendly behaviours compared to their peers who received traditional instruction. Similarly, Johnson (2019) found that digital learning tools could significantly improve academic outcomes while simultaneously promoting social and environmental responsibility.

Despite the encouraging findings from recent studies, several gaps remain in the literature. First, while many studies have highlighted the benefits of digital technology in enhancing academic performance, there is limited research focusing specifically on early childhood education in the age group of 5 to 8 years. This is a critical oversight, as this developmental stage is essential for establishing long-term cognitive, social, and environmental attitudes.

Second, the majority of existing studies have examined the use of VR and AR in isolated educational contexts without considering their potential to simultaneously address academic and environmental learning objectives. There is a need for integrative studies that assess the dual impact of these technologies on both learning outcomes and environmental stewardship. Such studies would provide a more comprehensive understanding of the potential synergies between digital innovation and sustainable education.

Third, while the theoretical benefits of immersive technologies are well-documented, empirical evidence regarding their long-term impact on environmental attitudes and behaviours remains sparse. Most studies have relied on short-term interventions or pilot programs, leaving questions about the sustainability of the observed outcomes. Moreover, few studies have incorporated the perspectives of key stakeholders—such as teachers and parents—which are crucial for the successful implementation of technology-driven educational strategies (Davis & Green, 2020).

Finally, there is a need to explore the practical challenges associated with integrating immersive digital technologies into early childhood education. These challenges may include issues related to cost, teacher training, curriculum development, and the technological infrastructure required to support VR and AR applications. Addressing these practical considerations is essential for translating the theoretical promise of digital and sustainable education into effective and scalable educational practices.

The theoretical framework presented in this section integrates constructivist and experiential learning theories with principles of environmental education, providing a robust foundation for the current study. By focusing on children aged 5 to 8, the study aims to bridge the gap between digital innovation and sustainable education. The literature reviewed herein underscores the potential of VR and AR to enhance academic outcomes and foster environmental awareness, while also highlighting significant gaps—particularly the need for integrative studies in early childhood settings and long-term assessments of behavioural change.

The present study is designed to address these gaps by employing an experimental methodology that compares immersive digital learning experiences with traditional instructional approaches. In doing so, it will capture not only the quantitative improvements in academic performance but also qualitative shifts in environmental attitudes and behaviours. The study also incorporates the perspectives of teachers and parents to offer a comprehensive view of both the opportunities and challenges associated with the integration of VR and AR technologies.

Moreover, the findings from this study are expected to have significant implications for educational practice and policy. By demonstrating that immersive digital technologies can be effectively harnessed to support both academic and sustainable education goals, the study will provide a model for integrating technology in early childhood curricula. Such integration is essential for preparing future generations to navigate an increasingly complex and environmentally challenging world. The implications extend beyond academic achievement to include the cultivation of a generation that is better equipped to engage with and address pressing environmental issues.

In summary, the integration of digital technology with sustainable education in early childhood is a multifaceted endeavor that draws on well-established learning theories and recent empirical findings. The theoretical framework outlined in this section emphasizes the importance of constructivist and experiential approaches, which are

particularly well-suited to immersive digital tools such as VR and AR. The literature reviewed indicates that these technologies hold considerable promise for enhancing both academic performance and environmental awareness among young learners. However, the current state of research reveals notable gaps—especially regarding the dual impact of these technologies in early childhood education and the need for stakeholder perspectives.

By addressing these gaps, the current study seeks to contribute valuable insights into how immersive digital experiences can transform early educational practices. The synthesis of digital innovation and sustainable education not only supports academic achievement but also promotes the development of environmentally conscious behaviours that are critical in today's world. Future studies building on this work should continue to explore long-term impacts, scalability, and the practical challenges of implementation, thereby paving the way for a more engaged, knowledgeable, and eco-conscious generation.

5. Methodology

7.1 Study Design

This study adopts a mixed-methods quasi-experimental design, integrating both quantitative and qualitative approaches to comprehensively examine the impact of Virtual Reality (VR) and Augmented Reality (AR) technologies in early childhood education for children aged 5 to 8.

The design involves a comparative analysis between an experimental group, which receives instruction enhanced by immersive digital technologies, and a control group, which follows conventional teaching methods. The mixed-methods approach is selected to quantify academic and environmental outcomes while simultaneously capturing in-depth insights into the perceptions of educators and parents (Creswell & Plano Clark, 2018; Selznick, 2024).

7.2 Study Community and Sample

7.2.1 Study Community

The study will be conducted with children aged 5 to 8 residing in the city of Jeddah, Saudi Arabia. Jeddah, as a major urban centre with a rich cultural heritage and diverse socio-economic backgrounds, offers a unique context to assess the impact of immersive digital technologies on academic learning outcomes and the development of environmental awareness among young learners. This localized focus allows for an in-depth exploration of how VR and AR applications are integrated into the educational experiences of children in Jeddah, thereby providing valuable insights that are directly relevant to the regional educational landscape.

7.2.2 Sample Selection

Children**:** A total of 60 children aged 5 to 8 years were recruited from two early childhood education institutions in Jeddah. A purposive sampling approach was used to select institutions that possessed the necessary infrastructure and willingness to implement immersive digital interventions. Within each institution, children meeting the inclusion criteria (appropriate age, ability to participate in classroom activities, parental consent, and absence of sensory or motor impairments) were identified. Eligible children were then randomly assigned into two equal groups:

- **Experimental Group (n ≈ 30):** Children who receive instruction incorporating VR and AR applications.
- **Control Group (n ≈ 30):** Children who receive traditional, non-digital instruction.

To ensure balanced representation, stratification by age (5–6 vs. 7–8 years) and gender was applied prior to random assignment.

Educators and Parents: A purposive sample of five educators and ten parents of the participating children was selected. Educators were chosen for their direct involvement with the target age group and willingness to integrate immersive tools, while parents were selected to provide complementary insights through semi-structured interviews.

This multi-level sampling strategy ensured methodological rigor by combining purposive selection of institutions with random and stratified assignment of children, while also integrating perspectives from educators and parents to enrich the interpretation of outcomes (Creswell & Plano Clark, 2018; Ahmed, 2024).

Group Equivalence: To establish baseline comparability, independent-samples t-tests were conducted on children's pre-test scores in academic performance and environmental awareness, while chi-square tests examined gender distribution. No statistically significant differences were observed ($p > .05$), confirming that the two groups were equivalent at baseline.

7.3 Data Collection Tools

7.3.1 Quantitative Tools – Environmental Awareness Assessment

A comprehensive environmental awareness assessment tool was developed to measure changes in children's environmental knowledge, attitudes, and sustainable behaviours. This tool combined a structured questionnaire with age-appropriate items and a pictorial Likert scale, and it was administered both before and after the intervention. The instrument was based on validated measures in early childhood education (Brown et al., 2021; Chawla & Cushing, 2022) and was specifically designed to capture the impact of VR and AR technologies on environmental awareness among children aged 5 to 8.

The tool addressed key components such as:

- understanding of environmental issues,
- attitudes toward sustainability, and
- Observable behaviours related to environmental care.

Steps of Tool Development: The initial pool of items was drafted based on a review of previous instruments and relevant literature. Items were then revised to suit the cognitive and linguistic level of 5–8-year-old children, making use of visuals and simplified wording. The draft version was presented to a panel of five experts in early childhood education and environmental studies to evaluate content validity. Their feedback guided refinements in wording, clarity, and cultural appropriateness.

Validity and Reliability: Content validity was ensured through expert review. A pilot test was conducted with five children (not part of the main sample) to check clarity and appropriateness of items. Internal consistency reliability was assessed using Cronbach's alpha, with results indicating acceptable reliability ($\alpha > 0.70$).

This directly answers the main study question focused on fostering environmental awareness.

7.3.2 Qualitative Tools – Semi-Structured Interviews

In-depth interviews were conducted with educators and parents to explore their perceptions regarding the integration of VR and AR technologies in the classroom. Interview guides were developed based on the sub-study questions, focusing on the perceived impacts on academic performance and environmental awareness, as well as on the challenges and opportunities encountered during implementation (Davis & Green, 2020).

Each interview lasted between 30 and 45 minutes and was audio-recorded with participants' consent.

Development of the Interview Guide: The initial set of open-ended questions was drafted from the study's conceptual framework and reviewed by three faculty experts to ensure alignment with the research objectives. Questions were refined to avoid leading prompts and to encourage free expression from participants.

Validity and Reliability: Content validity was established through expert review, confirming that the questions adequately addressed the constructs under investigation. A pilot interview was conducted with one educator and one parent (outside the main sample) to assess clarity, flow, and appropriateness of the questions. Minor adjustments were made based on feedback, thereby improving the tool's reliability and trustworthiness.

7.4 Data Analysis Procedures

7.4.1 Quantitative Data Analysis

The quantitative data were analysed using the Statistical Package for the Social Sciences (SPSS, v.28). Prior to the main analyses, the dataset was screened to identify any missing values, outliers, or data-entry errors. Statistical assumptions of normality, homogeneity of variance, and linearity were also checked to ensure the suitability of the planned tests (Creswell & Plano Clark, 2018).

Descriptive statistics, including means, standard deviations, and frequency distributions, were computed to summarize participants' demographic characteristics and to provide an overview of baseline academic performance and environmental awareness scores. This step allowed for the establishment of a clear profile of the experimental and control groups before the intervention (Ahmed, 2024).

To examine the study hypotheses, inferential statistical techniques were employed. Paired-samples t-tests were conducted to measure within-group changes between pre- and post-test scores, while independent-samples t-tests and analysis of covariance (ANCOVA) were used to assess differences between the experimental and control groups after the intervention, controlling for baseline performance. Effect sizes, such as Cohen's d and partial eta squared, were calculated to determine the magnitude of the observed effects and to complement statistical significance testing (Smithies, 2024).

Finally, the reliability of the environmental awareness questionnaire was evaluated using Cronbach's alpha, which demonstrated acceptable levels of internal consistency. The validity of the instrument was supported through expert review and pilot testing with a small sample prior to the main study (Creswell & Plano Clark, 2018). These steps ensured that the measures were both reliable and valid, thereby strengthening the robustness of the quantitative findings.

7.4.2 Qualitative Data Analysis

Verbatim transcripts of interviews and focus groups were analysed using thematic analysis following Braun and Clarke's (2019) systematic framework. NVivo software was employed to facilitate coding, categorization, and theme development in a structured and transparent manner. To enhance interpretive accuracy, member checking was conducted by sharing preliminary interpretations with participants, ensuring that the extracted meanings faithfully reflected their intended perspectives. Methodological triangulation was also achieved by integrating qualitative insights with the quantitative findings, which strengthened the credibility and internal validity of the results (Creswell & Plano Clark, 2018). These procedures collectively enhanced the trustworthiness of the analysis and provided a rigorous basis for interpretation. Ultimately, this process enabled a nuanced understanding of both the pedagogical potential and the practical challenges of integrating VR/AR technologies into early childhood education.

7.5 Ethical Approval and Participant Protection

Written informed consent was obtained from all participating teachers and parents, and assent was secured from the children in an age-appropriate manner. Data were anonymized and stored securely to ensure confidentiality. Given the use of immersive technologies, possible risks such as motion sickness or overstimulation were carefully monitored, with immediate measures in place to address any adverse effects. The study followed established international ethical guidelines for research involving children.

6. Results

Quantitative Results:

The quantitative analyses of data collected from 60 children aged 5 to 8 provided robust evidence in favor of using immersive digital technologies—namely VR and AR—in early childhood education. The sample was equally divided into two groups:

- Experimental Group (n = 30): Children who received instruction incorporating VR and AR applications.
- Control Group (n = 30): Children who received traditional, non-digital instruction.

Regarding Academic Performance and Environmental Awareness, standardized tests administered before and after the intervention revealed that the experimental group achieved significantly higher gains in both academic performance and environmental awareness compared to the control group. Specifically, the experimental group exhibited an average 15% increase in overall academic performance (spanning mathematics, literacy, and problem-solving skills) from pre- to post-intervention, while the control group showed only a 4% improvement. Furthermore, the Environmental Awareness Assessment Tool indicated that the experimental group's post-intervention scores were approximately 20% higher than their pre-intervention scores, compared to a modest 4% increase in the control group.

The results are summarized in Table 1 below:

Table 1. Comparison of Academic Performance and Environmental Awareness Scores

Group	Academic Pre	Academic Post	% Increase (Academic)	Environmental Pre	Environmental Post	% Increase (Environmental)
Experimental Group	30	35	15%	25	30	20%
Control Group	30	31	4%	25	26	4%

The data clearly indicate that children in the experimental group not only achieved higher academic gains but also developed a significantly enhanced environmental awareness. The 15% improvement in academic performance and the 20% increase in environmental awareness for the experimental group suggest that the immersive digital experiences provided by VR and AR made abstract academic concepts and environmental issues more tangible and engaging. In contrast, the control group, which relied on traditional instruction, exhibited only minimal improvements.

These findings support the hypothesis that the integration of immersive technologies in early childhood education can lead to substantial gains in both cognitive and affective domains. The statistically significant improvements observed in the experimental group align with previous research (Kim & Lee, 2021; Wang et al., 2020), underscoring the potential of VR and AR applications to transform the learning environment by enhancing both academic outcomes and environmental consciousness.

Qualitative Results:

In-depth semi-structured interviews were conducted with educators and parents to explore their perceptions of integrating VR and AR technologies into early childhood education. Thematic analysis of the interview data revealed three primary themes:

- **Enhanced Engagement and Learning Outcomes:**

  Educators and parents consistently reported that the use of immersive technologies significantly increased children's engagement during classroom activities. Educators observed that children became more attentive, actively participated in interactive lessons, and demonstrated improved retention of academic concepts. Parents noted that their children showed heightened enthusiasm for learning and were more eager to discuss new topics introduced through VR and AR experiences.

- **Improved Environmental Awareness:**

  Participants indicated that immersive digital experiences made abstract environmental concepts more tangible for young learners. Educators explained that VR and AR simulations enabled children to visualize complex environmental issues, thereby deepening their understanding of topics such as climate change and resource conservation. This enhanced comprehension translated into more proactive and responsible attitudes toward sustainability, as noted by both teachers and parents.

- **Implementation Challenges and Considerations:**

  Despite the noted benefits, several challenges were identified. Both educators and parents expressed concerns about technical difficulties, the limited availability of high-quality, age-appropriate content, and potential risks associated with excessive screen time. Educators emphasized the need for comprehensive training and ongoing support to effectively integrate these technologies into the curriculum, while parents stressed the importance of structured supervision to ensure that immersive experiences complemented traditional learning methods.

  Overall, the qualitative findings suggested that the integration of VR and AR technologies in early childhood education could enhance both academic engagement and environmental awareness. However, the data also underscored the need for careful planning, adequate teacher training, and stringent supervision to address implementation challenges and maximize the positive impacts of these immersive tools.

Triangulated Findings and Answers to the Study Questions:

Findings from the qualitative data were triangulated with the quantitative results to provide a comprehensive understanding of the study outcomes. This mixed-methods integration enhanced the validity of the findings by corroborating evidence from multiple sources. The following sections address the main study question and its sub-questions.

Main Study Question

How does the integration of VR and AR technologies in early childhood education (aged 5 to 8) affect the development of environmental awareness compared to traditional teaching methods?

Quantitative data revealed that children in the experimental group, who received instruction with VR and AR applications, showed a significant improvement in environmental awareness scores compared to the control group. Specifically, the Environmental Awareness Assessment Tool indicated that post-intervention scores increased by approximately 20% in the experimental group, while the control group exhibited only a modest 4% improvement. Qualitative feedback from semi-structured interviews reinforced these findings: educators and parents reported that immersive digital experiences helped children grasp abstract environmental concepts more concretely, thereby

enhancing their overall understanding and engagement with sustainability issues. The triangulated results consistently demonstrated that the integration of VR and AR technologies markedly improved environmental awareness among early childhood learners compared to traditional teaching methods.

Sub-Question 1

How do immersive digital experiences provided by VR and AR influence the development of environmental awareness and responsible behaviour toward sustainability in early childhood learners?

The quantitative outcomes indicated a significant elevation in environmental awareness among children exposed to VR and AR, as measured by the pre- and post-intervention assessments. Children in the experimental group not only increased their scores but also exhibited behaviours associated with environmental responsibility, such as improved attentiveness to sustainability topics and proactive discussions during classroom activities. Qualitative insights provided by educators and parents further illuminated these effects; they observed that immersive experiences enabled children to visualize environmental issues such as climate change and resource conservation, which in turn fostered a deeper understanding and more responsible behaviour toward sustainability. Together, the data suggested that immersive digital experiences played a critical role in promoting both cognitive and behavioural aspects of environmental awareness in early childhood.

Sub-Question 2

What are the perceptions of teachers and parents regarding the effectiveness, challenges, and opportunities associated with integrating VR and AR technologies in early childhood education?

The qualitative findings from semi-structured interviews revealed that teachers and parents generally perceived the integration of VR and AR technologies as highly effective in enhancing the educational experience. Educators noted that these technologies increased student engagement, enriched classroom discussions, and improved overall learning outcomes, particularly in relation to environmental education. Parents echoed these sentiments, reporting observable improvements in their children's curiosity, environmental knowledge, and responsible behaviour. However, both groups also identified several challenges. They expressed concerns about the potential for technical difficulties, the necessity for age-appropriate content, and the risks of excessive screen time. Furthermore, educators stressed the need for comprehensive training and ongoing support to effectively incorporate these technologies into their teaching practices. Despite these challenges, the overall perception was that the benefits of VR and AR integration—namely, enhanced engagement and deeper environmental understanding—outweighed the potential drawbacks, thereby offering significant opportunities for the future of early childhood education.

In summary, the triangulated findings confirmed that the integration of VR and AR technologies in early childhood education significantly enhanced the development of environmental awareness compared to traditional methods. Immersive digital experiences not only improved academic and environmental outcomes but also positively influenced children's responsible behaviours toward sustainability. At the same time, the perceptions of educators and parents highlighted both the effectiveness of these technologies and the practical challenges that must be addressed to optimize their integration in educational settings.

7. Discussion

This study examined the integration of VR and AR technologies in early childhood education for children aged 5 to 8 in Jeddah, focusing on their effects on the development of environmental awareness compared to traditional teaching methods. The triangulated findings—derived from both quantitative assessments and qualitative

interviews—provided robust evidence that immersive digital experiences substantially enhanced environmental awareness and academic performance among young learners.

Quantitative results demonstrated that children in the experimental group experienced significant improvements in both academic achievement and environmental awareness. Specifically, standardized tests revealed that the experimental group's academic performance increased by an average of 15%, while their environmental awareness scores improved by approximately 20% post-intervention. In contrast, the control group, which received traditional, non-digital instruction, showed only modest gains of 4% in both domains. These statistically significant differences suggest that the immersive nature of VR and AR applications enabled children to better grasp abstract concepts, particularly those related to environmental issues.

Qualitative data collected through semi-structured interviews with educators and parents further enriched these findings. Educators observed that VR and AR experiences rendered environmental topics—such as climate change, resource conservation, and sustainability—more tangible and engaging. They reported that children exposed to these technologies were more proactive in classroom discussions and demonstrated increased curiosity about environmental issues. Parents corroborated these observations, noting that their children were more inclined to discuss environmental topics at home and exhibited behaviours that reflected a deeper understanding of sustainability principles.

The mixed-methods approach allowed for a comprehensive analysis of the study outcomes. The quantitative improvements in environmental awareness were consistently supported by qualitative insights, which highlighted the mechanisms by which immersive technologies fostered both cognitive and affective learning. The experiential nature of VR and AR allowed children to visualize complex environmental processes and thus internalize these concepts more effectively—a finding that aligns with previous research emphasizing the benefits of experiential learning in early education (Davis & Green, 2020; Kim & Lee, 2021).

Despite these positive outcomes, the study also identified several challenges. Both educators and parents expressed concerns regarding technical difficulties, the need for high-quality, age-appropriate digital content, and the potential adverse effects of prolonged screen time. These concerns underscored the importance of comprehensive teacher training, structured supervision, and the careful design of immersive content to ensure that the benefits of VR and AR technologies are maximized while minimizing any negative impacts.

The implications of these findings are multifield. First, they suggest that immersive digital technologies can serve as powerful tools in early childhood education—not only by enhancing academic performance but also by cultivating environmental awareness and responsible behaviour toward sustainability. This dual impact is particularly critical in the context of global environmental challenges and the need for sustainable development education from an early age. Second, the results advocate for the incorporation of immersive technologies into early childhood curricula as a means of complementing traditional teaching methods, thereby providing a more engaging and effective learning environment. Finally, the identified challenges call for ongoing research and investment in teacher training and content development to ensure the safe and effective implementation of these technologies.

In conclusion, the integration of VR and AR technologies in early childhood education was found to significantly enhance both academic performance and environmental awareness. The triangulated data provided compelling evidence that immersive digital experiences make abstract concepts more accessible and engaging, ultimately fostering a deeper understanding of sustainability among young learners. These findings contribute to the growing body of literature on digital education and environmental sustainability, and they offer valuable guidance for educators, policymakers, and researchers seeking to leverage immersive technologies to improve learning outcomes in early childhood settings.

8. Limitations, Recommendations and Future Directions

10.1 Limitations

This study faced several limitations that should be acknowledged. First, the sample size was relatively small, consisting of 60 children from a single urban area (Jeddah), which may have limited the generalizability of the findings to other regions or populations. Additionally, the study employed a cross-sectional design, which provided only a snapshot of the immediate impacts of VR and AR integration without capturing long-term outcomes.

10.2 Recommendations

Based on the study findings, several recommendations were proposed to enhance the effective integration of immersive digital technologies in early childhood education:

- **Teacher Training and Support:** It is recommended that comprehensive professional development programs be implemented to equip educators with the technical skills and pedagogical strategies necessary for effectively integrating VR and AR into their teaching practices. Such training would ensure that teachers are not only able to operate these technologies but also align them with curricular goals.

- **Development of Age-Appropriate Content:** Collaboration among educators, early childhood specialists, child psychologists, and technology developers is essential to design sustainable, age-appropriate digital learning environments. These environments should include the development of age-appropriate educational content, where educators, content developers, and child psychologists work together to create high-quality VR and AR content. This content should be designed to make abstract environmental concepts tangible and engaging, while also safeguarding against potential negative effects, such as exposure to inappropriate material or overuse.

- **Enhanced Supervision and Structured Guidelines:** The study underscored the need for structured supervision protocols to monitor and regulate the use of immersive technologies in the classroom. Establishing clear guidelines and limits on screen time would help mitigate risks and ensure that digital experiences complemented rather than replaced traditional learning methods.

- **Parental Involvement:** Recommendations also emphasized the importance of engaging parents through informational sessions and workshops. Educating parents on the benefits and potential challenges of VR and AR applications would foster a supportive home environment that reinforced the learning outcomes achieved in the classroom.

10.3 Future Directions

Future research should address the limitations of the current study and build on its findings in several ways:

- **Larger and More Diverse Samples:** Subsequent studies should aim to recruit larger and more diverse samples across multiple regions to enhance the generalizability of the findings. This would allow for a better understanding of how cultural and socio-economic factors influence the effectiveness of immersive digital technologies in early childhood education.

- **Longitudinal Studies:** Future research would benefit from adopting longitudinal designs to examine the sustained impact of VR and AR integration on academic performance, environmental awareness, and other developmental outcomes over time. Longitudinal data could provide insights into the long-term benefits and potential drawbacks of these technologies.

- **Broader Outcome Measures:** Expanding the scope of outcome measures to include social, emotional, and behavioural development would provide a more comprehensive picture of how immersive technologies affect early

childhood education. Investigating these additional dimensions could inform more holistic educational interventions.

- **Comparative Studies:** Future investigations might compare different types of immersive technologies or instructional models to determine which approaches yield the most effective outcomes for various educational objectives. Such comparative studies could guide the development of best practices for integrating digital tools into early curricula.

By addressing these limitations and pursuing the recommended future research directions, stakeholders can further optimize the use of VR and AR technologies in early childhood education, thereby enhancing both academic achievement and environmental awareness among young learners.

11. Conclusion

This study examined the integration of VR and AR technologies in early childhood education for children aged 5 to 8, focusing on their impact on academic performance and the development of environmental awareness. The findings demonstrated that immersive digital experiences significantly enhanced both cognitive outcomes and the understanding of sustainability concepts compared to traditional teaching methods. Children in the experimental group exhibited notable improvements in standardized academic assessments and environmental awareness scores, while qualitative insights from educators and parents underscored increased engagement and a deeper connection to environmental topics.

Despite these promising results, the study also revealed several challenges, including the need for high-quality, age-appropriate content, comprehensive teacher training, and structured supervision to mitigate potential adverse effects. These limitations point to the importance of adopting a balanced and well-supported approach when incorporating immersive technologies into early childhood curricula.

Overall, the study contributes to the growing body of evidence supporting the transformative potential of VR and AR in education. It highlights that, when effectively implemented, immersive digital tools can foster not only academic excellence but also responsible environmental behaviour among young learners. Future research should build on these findings by exploring long-term impacts and broadening the scope of developmental outcomes, thereby paving the way for more innovative and sustainable educational practices.

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التقنيات الرقمية الإنغماسية في تعليم الطفولة المبكرة: تعزيز الوعي البيئي والاستدامة

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المستخلص:

تتطور التكنولوجيا الرقمية بسرعة وتعيد تشكيل العديد من جوانب الحياة، بما في ذلك تعليم الطفولة المبكرة. وقد بحثت هذه الدراسة في تأثير التجارب الرقمية الغامرة – وخاصة الواقع الافتراضي والواقع المعزز – على تعزيز الوعي البيئي وتشجيع السلوكيات المستدامة بين الأطفال الذين تتراوح أعمارهم بين ٥ و٨ سنوات في جدة، المملكة العربية السعودية. باستخدام تصميم المنهجية المختلطة، تمت مقارنة الأطفال الذين يتلقون تعليم الواقع الافتراضي والواقع المعزز مع أولئك الذين يتلقون طرقًا تقليدية غير رقمية. كشفت التقييمات الكمية أن المجموعة التجريبية أظهرت مكاسب أعلى بكثير في الوعي البيئي، حيث تشير المقاييس الموحدة إلى تحسن متوسط بنحو ٢٠٪ مقارنة بزيادة متواضعة بنسبة ٤٪ في المجموعة الضابطة. كما دعمت البيانات النوعية، التي تم جمعها من خلال مقابلات شبه منظمة مع المعلمات وأولياء الأمور. كما أفاد المشاركون أن التجارب الرقمية الغامرة لم تزيد من المشاركة في موضوعات الاستدامة فحسب، بل إنها عمقت أيضًا فهم القضايا البيئية المعقدة مثل تغير المناخ والحفاظ على الموارد وإدارة الموارد الطبيعية. ولاحظ المعلمون أن هذه التقنيات ساعدت في إزالة الغموض عن المفاهيم البيئية المجردة، مما مكن الأطفال من التواصل مع الطبيعة بطريقة ملموسة، في حين لاحظ الآباء شعورًا متزايدًا بالمسؤولية البيئية والمواقف الاستباقية تجاه الاستدامة بين أطفالهم. وبشكل عام، تؤكد الدراسة على إمكانات التقنيات الغامرة لدعم أهداف التنمية المستدامة من خلال مواءمة الممارسات التعليمية مع المسؤولية البيئية. وبناءً على هذه النتائج، توصي الدراسة بتعاون التربويين ومتخصصي الطفولة المبكرة وعلماء نفس الأطفال مع مبرمجي التكنولوجيا لتصميم بيئات تعليمية رقمية مستدامة ومناسبة للأعمار، تدمج التعليم البيئي بشكل فعال في مناهج التعلم المبكر.

الكلمات الرئيسية:

الطفولة المبكرة ؛ التعليم المبكر المستدام ؛ التكنولوجيا التعليمية ؛ الواقع الافتراضي (VR) ؛ الواقع المعزز (AR) ؛ تطوير الوعي البيئي ؛ التجارب الرقمية الإنغماسية أو الغامرة ؛ أهداف التنمية المستدامة (SDGs)