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Examining the Impact of Augmented Reality Texts on Students' Attitudes Toward Environmental Issues and Sustainable Development

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Abstract

This study aims to compare the levels of environmental awareness within the context of environmental issues and sustainable development between two groups of students—those who read AR-supported texts and those who read paper-based texts. The participants consisted of 147 secondary school students aged between 11 and 12. In the pre-test phase, both the experimental and control groups read the texts in a paper-based format, after which two different scales were administered as pre-tests. In the post-test phase, the control group continued with the paper-based reading activity, while the experimental group read the augmented reality-supported texts using tablets. The same scales were re-administered as post-tests to both groups. Data collected during the research process were analyzed using paired samples *t*-tests and independent-samples *t*-tests. The pre-test results did not indicate a statistically significant difference between the experimental and control groups. However, the post-test results revealed that the augmented reality intervention more effectively supported students' attitudes toward environmental issues and their environmental awareness within the context of sustainable development, compared to traditional text reading. These findings suggest that AR-supported texts have significant potential in fostering positive student attitudes toward environmental issues and enhancing environmental awareness in the context of sustainable development. In future studies, examining AR-supported applications in comparison with other digital tools and across various age groups may yield more comprehensive results regarding environmental awareness and education for sustainable development.

Keywords: augmented reality storybooks; paper reading; sustainable development; environmental problems; secondary school students

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1. Introduction

In recent years, environmental issues have become an increasingly pressing global concern. Factors such as population growth, industrialization, and urbanization have intensified environmental degradation, thereby making it more important than ever for individuals to develop conscious and responsible attitudes toward these problems [1–4]. Issues such as climate change, the loss of biodiversity, depletion of natural resources, pollution, and waste management necessitate urgent solutions in order for humanity to achieve a sustainable future [5–11]. Accordingly, processes aimed at raising awareness and shaping attitudes toward the resolution of environmental problems have become central to both national and international policy agendas [12]. In this context, education and

activities that aim to increase individual awareness play a critical role [13]. Environmental awareness acquired especially during childhood significantly shapes individuals' future attitudes and behaviors [14,15]. In this context, raising environmental awareness among middle school students holds strategic importance for cultivating individuals who will adopt sustainable living practices in the future. In this regard, the present study aims to contribute to enhancing students' awareness of sustainability issues by emphasizing the United Nations Sustainable Development Goals of "Quality Education," "Responsible Consumption and Production," and "Climate Action."

Environmental education emerges as a significant tool for cultivating individual sensitivity to environmental problems [16,17]. As emphasized by the United Nations [18], delivering environmental education effectively and encouraging individuals to develop positive attitudes in this regard are essential for achieving the goals of sustainable development. In this respect, education for sustainable development is seen as a vital area that can contribute to societal transformation through the promotion of environmental awareness [19,20]. Environmental education content and practices offered at the middle school level contribute not only to increasing students' knowledge but also to raising them as individuals who are more sensitive to environmental issues [21,22]. Research emphasizes the importance of starting environmental education at an early age. It has been found that delivering environmental education at the middle school level supports the development of students into more sensitive, critical, and solution-oriented individuals in response to environmental problems [23,24]. Therefore, raising environmental awareness should not be limited to knowledge-based instruction; it must also be implemented through interactive and student-centered approaches that aim to bring about behavioral change. Therefore, the quality of the methods, techniques, and materials used in environmental education are of great importance for enhancing its effectiveness. At this point, technology-enhanced instructional practices offer various opportunities for making learning processes more effective and interactive [25].

Rapid advancements in information and communication technologies have led to profound transformations across numerous domains, including education [26]. This digital transformation in education has rendered learning environments more dynamic, interactive, and student-centered [27]. Given these developments, digital technologies—particularly augmented reality (AR)—have emerged as heralds of a new era in education [28]. AR technology enables the integration of digital content with the physical environment, thereby allowing students to simultaneously engage with real-world and virtual elements [29,30]. Through such capabilities, AR provides learners with opportunities to visualize abstract concepts, explore complex phenomena, and engage in interactive learning scenarios [31,32].

Recent research on the use of AR technologies in the context of environmental education has demonstrated its potential to enhance students' environmental awareness, foster positive attitudes, and increase motivation to learn [33–37]. In particular, AR's capacity to promote children's visual and interactive engagement with environmental issues positions it as a critical tool for environmental education [38–44]. For this reason, the early implementation of innovative educational tools such as AR is important for raising environmentally conscious individuals. Indeed, several studies focusing on the use of AR technologies to address environmental issues have indicated that technology-assisted practices increase students' interest in the environment and contribute to the development of positive attitudes toward environmental topics [40,43,45–47]. However, the main distinction of this study from previous research lies in its comparative examination of the effects of augmented reality-supported reading activities on students' attitudes toward environmental issues and their level of environmental awareness within the context of sustainable development, compared to paper-based reading activities. In this way, studies conducted in the school en-

vironment will contribute to the development of students' awareness and positive attitudes toward the environment across multiple dimensions. In this context, the present study aims to examine the impact of AR-supported learning materials on students' attitudes toward environmental problems and their awareness of sustainability. The results of this study can be compared with findings from other AR-based research and are expected to contribute to a better understanding of how such applications affect different student populations.

1.1. Literature Review

1.1.1. Augmented Reality in Education

AR is an innovative technology that enhances user experience by integrating digital content into the physical world. In recent years, the use of this technology, especially in the field of education, has gained significant momentum [48]. While Barsom, Graafland, and Schijven [49] define AR as an interactive virtual layer superimposed on reality, Liberati [29] emphasizes that AR allows users to interact with digital content without focusing on screens.

Current literature suggests that AR applications may reduce learning material costs while improving learning outcomes [50,51]. Moreover, findings indicate that AR-supported learning environments foster personalized and diverse learning experiences [52–59]. In this context, AR technology enhances students' motivation and satisfaction with learning and contributes to the development of self-regulation skills [60–63]. Indeed, the effects of AR are realized through concrete applications such as offering personalized content that supports students' learning pace, incorporating interactive applications that appeal to multiple senses, and presenting real-life scenarios through three-dimensional modeling [32,49]. Accordingly, such applications enable AR to make the learning process more personalized and enriched; thus, it can be said that they help enhance students' motivation and satisfaction levels by encouraging their active participation in the learning process [64,65]. However, AR technology also has limitations. Excessive focus on virtual information, increased cognitive load, and difficulties in perceiving overlapping content are among its notable drawbacks [66,67]. Nonetheless, the results of relevant studies in the literature indicate that AR is a notable innovation in education, attracting attention from both researchers and educators [68–70]. Within this framework, it is argued that AR applications can be effective in education and enrich the learning process [71]. Particularly, in interdisciplinary fields such as environmental education, the visual and interactive environments offered by AR are considered to provide significant opportunities. However, to fully understand the potential benefits and limitations of AR in education, further research is needed [67,72,73].

In recent years, the world has been confronted with pressing environmental challenges such as climate change, loss of biodiversity, water scarcity, and waste management. Raising public awareness and providing education play a crucial role in addressing these issues [74]. In this regard, AR technology can serve as an innovative tool for raising awareness of environmental problems and supporting efforts to achieve sustainable development goals. Indeed, AR can contribute to concretizing information about environments that children cannot physically access, such as areas with high levels of environmental pollution and waste, or natural settings that are risky to experience firsthand due to geographical conditions. Therefore, by providing visual support and opportunities for interaction, AR can enhance the effectiveness of conveying the potential destruction caused by environmental problems and the importance of sustainability to students [41,75,76]. Some studies have shown that AR technology positively influences environmental attitudes and fosters greater empathy among students toward environmental issues [77,78]. Similarly, Bekaroo et al. [79] have indicated that AR technology is effective in raising awareness about the sustainable use of electronic devices. Although some research has been conducted in this area, the

number of studies is still relatively limited compared to other fields [35,46,80,81]. Therefore, examining the impact of AR applications on these issues is deemed necessary. Accordingly, this study addresses the applicability of AR technology in enhancing students' awareness of environmental issues and sustainable development.

1.1.2. The Use of AR in Raising Awareness of Environmental Problems

Education holds critical importance in fostering environmental awareness and developing sustainable life skills in individuals [82]. Integrating environmental issues into curricula across all levels of education—from early childhood to higher education—contributes to raising environmentally sensitive generations [83,84]. Environmental education aims not only to help students understand current problems but also to equip them with the knowledge and skills necessary to effectively combat such issues [85]. In this context, it is essential that instructional materials be selected in ways that clarify environmental problems and enhance understanding [86,87]. In particular, reading texts—commonly used instructional tools—can help concretize abstract environmental issues, thereby increasing student awareness and promoting broader social sensitivity. However, the assumption that individuals will develop sustainable life skills or directly acquire the competence to cope with environmental problems through environmental education is open to criticism, particularly in the context of the gap between environmental attitudes and pro-environmental behaviors. As emphasized in the study by Kollmuss and Agyeman [88], having environmental knowledge and awareness does not guarantee that individuals will translate this knowledge and awareness into environmentally responsible behaviors. The study revealed that there is no direct or simple relationship between environmental knowledge and behavior; rather, such behaviors are shaped by the complex interplay of numerous internal and external factors.

The rapid advancements in information and communication technologies in recent years have necessitated the transformation of traditional educational approaches to meet evolving needs [89]. As a result of this transformation, students today can access learning content anytime and anywhere through mobile learning applications, while digital technologies are reshaping the nature of educational tools by integrating with physical systems [90,91]. Within this framework, the integration of AR technology into educational environments offers students innovative opportunities to understand the complex structure of the digital age and adapt to it accordingly.

AR is a technology that supports learning by enabling users to see their real environment while overlaying virtual elements upon it; rather than replacing reality, it aims to enhance it [92]. In this respect, AR technology merges real and virtual environments, thus becoming a supportive tool for both classroom-based and mobile learning [93]. As a result, students move from passive information reception to active exploration, gaining the opportunity to internalize and apply knowledge related to their environment [94,95]. In this regard, AR-supported reading texts stand out as effective and innovative tools that can be used in the teaching of environmental problems. Texts enhanced with AR technology provide students with an interactive and tangible learning experience, making it possible to convey abstract subjects such as environmental issues in a more comprehensible and engaging manner [76,96–99].

In conclusion, the visual and interactive affordances of AR-supported texts demonstrate strong potential in increasing awareness of environmental problems and contributing to the achievement of sustainable development goals. Therefore, the present study focuses on examining the effects of AR-enhanced texts in raising awareness among secondary school students regarding environmental problems and supporting the construction of a sustainable future.

1.1.3. The Use of AR in the Context of Sustainable Development

Sustainable development is defined as a holistic development model that seeks to balance environmental, economic, and social dimensions while ensuring harmony between humanity and nature. The concept was first introduced in the 1987 Brundtland Report published by the United Nations World Commission on Environment and Development, where it was described as development that meets the needs of the present without compromising the ability of future generations to meet their own needs [100]. This definition emphasizes the necessity of considering the rights of future generations when utilizing current natural resources [101]. Sustainable development is not limited to the efficient use of environmental resources; it also encompasses the promotion of social justice and the maintenance of economic stability [102]. Accordingly, sustainable development includes multidimensional goals such as maintaining ecological balance, ensuring equitable income distribution, and making economic growth sustainable [103–106].

The United Nations' 2030 Agenda for Sustainable Development, adopted in 2015, outlined 17 core goals aimed at eradicating poverty, protecting the planet, and promoting prosperity for all [107]. One of these goals, "quality education," calls for strengthening education at all levels, in alignment with sustainable development. In this context, the UN encourages its member states to restructure their education systems in accordance with the objectives of sustainable development [108]. However, according to UNESCO [83], sustainable development-oriented education has yet to be effectively implemented across all educational levels.

The literature suggests that individuals' awareness of sustainability and the translation of that awareness into behavioral change can be achieved through education [109–111]. Education not only raises environmental awareness but also supports individuals in adopting sustainable lifestyles and developing attitudes that contribute to broader social transformation [112,113]. In this regard, innovative teaching methods and technological tools play an essential role in enhancing the impact of education for sustainable development. In particular, AR technology has emerged as an innovative tool that enriches students' learning experiences by integrating digital content into the physical environment [114]. Through AR, abstract and complex sustainability concepts can be rendered more tangible and comprehensible for students [115]. This statement encompasses the concretization—through AR technology—of concepts that may be abstract for children who have not directly experienced issues such as climate change, environmental degradation, depletion of natural resources, and social injustice, which are all addressed within the context of sustainability. AR makes this possible through the integration of sound, video, 3D, and interactive content [32,116,117]. For example, with AR-supported applications, students can partially calculate their own carbon footprints and observe their environmental impacts through augmented graphics and simulations. The water cycle can be concretized and taught through three-dimensional animations. Waste separation and recycling processes can be experienced hands-on through task-based AR scenarios, while the consequences of environmental threats—such as biodiversity loss due to deforestation—can be observed via simulated natural environments. Such applications not only enable students to acquire knowledge, but also allow them to perceive and internalize concepts related to the environment and sustainability in a multidimensional way [37,118,119].

1.2. The Current Study

In this study, the aim was to compare the levels of environmental awareness in the context of sustainable development and attitudes toward environmental problems between two groups of students: those who engaged in AR-supported reading activities and those

who participated in paper-based reading activities. This study addresses the following research questions:

1. What is the difference in the scores obtained from the Attitude Toward Environmental Problems Scale between students who participated in AR-supported reading activities and those who participated in paper-based reading activities?
2. What is the difference in the scores obtained from the Environmental Awareness Scale in the context of sustainable development between students who participated in AR-supported reading activities and those who participated in paper-based reading activities?

2. Materials and Methods

2.1. Participants

The participants in this study consisted of 147 sixth-grade students, aged between 11 and 12, enrolled in a public secondary school located in Antalya, Türkiye. The sample size was determined through a power analysis conducted using the G*Power software 3.1.9.7. After obtaining the necessary ethical approvals, the study group was formed exclusively from students who voluntarily agreed to participate in the research. Prior to this study, formal permissions were secured from the school administration, and informed consent forms were obtained from the parents of the students.

Following the approval process, 73 students were assigned to the experimental group and the remaining 74 to the control group. The students were randomly assigned to either the experimental or control group. Demographic information regarding the study participants is presented in Table 1.

Table 1. Demographic characteristics of the participants.

Demographic Information		Experimental Group		Control Group	
		N	%	N	%
Age	11	33	45.2	30	40.5
	12	40	54.8	44	59.5
Gender	Male	35	47.9	36	48.6
	Female	38	52.1	38	51.4

2.2. The Augmented Reality Storybook

Within the scope of this study, four AR-supported texts were developed to inform students about environmental issues and to engage their interest through motivating content. These texts were titled Environmental Pollution, We Recycle Waste, We Use Renewable Energy, and I Love Nature. The texts were designed to emphasize the significance of environmental problems and sustainability. In addition, relevant visual materials were integrated into the texts to support the content and enhance the immersive experience. These visuals were also utilized to generate the AR components.

Following the preparation of the texts and visuals, compatible AR content was developed. Ensuring alignment between the textual content and the AR materials was considered crucial, as inconsistencies between digital and textual elements can hinder comprehension. Therefore, digital content featuring engaging visuals related to environmental pollution, waste, renewable energy, and nature was carefully designed to align with the texts.

Moreover, design principles proposed by Şimşek et al. [66] for the coherent and balanced integration of multimedia content into AR-supported texts were taken into account. These principles guided the development of AR content aimed at enhancing reading comprehension and reducing cognitive load. The duration of the AR experiences ranged from 24 to 27 s. To further enhance the learning experience, the AR videos were voice-narrated

in alignment with the corresponding textual sections. The segments narrated in the video were removed from the reading texts. The AR content, triggered visually during reading, was consistent with the flow of the text. It represented a complete and coherent text together with the preceding and following parts.

Upon completion of the video production process, the visuals and videos were integrated into an AR platform. Each text was paired with one visual and one video. For this purpose, the Roar AR (https://theroar.io/) application was employed to match the videos and visuals embedded in the texts. When the application was launched on a mobile device, the camera was activated, and the AR content was triggered upon recognition of the relevant visual marker. As a result, during the reading activity, students were able to engage with printed texts while simultaneously interacting with the AR components through tablets, without requiring any prior knowledge of coding or computer programming. The visuals related to the reading activities conducted through augmented reality applications are presented in Figure 1.

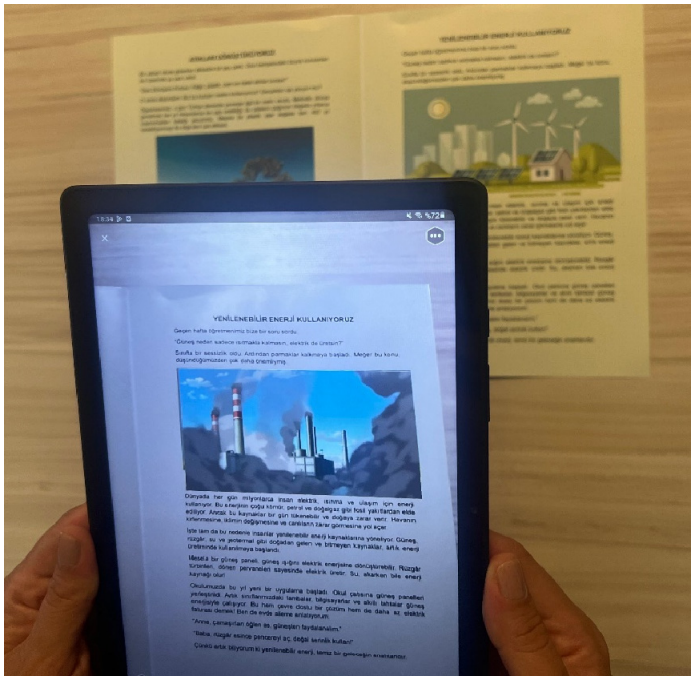


Figure 1. Screenshots from the application.

2.3. Measures

2.3.1. Attitude Toward Environmental Problems Scale

This scale was developed by Kılıç and Kan [120] to assess secondary school students' attitudes toward environmental problems. It consists of three components: cognitive, affective, and behavioral. The scale was chosen for this study because it was appropriate for the proficiency level of the study group, had the capacity to comprehensively assess students' environmental attitudes across cognitive, affective, and behavioral dimensions, and demonstrated strong validity and reliability, making it a robust measurement tool. The scale includes a total of 22 items, which are grouped under four factors: negative affective responses toward the environment, environmental awareness [cognitive], environmental protection behaviors, and positive affective responses toward the environment. The scale items were rated using a 5-point Likert scale (1—strongly disagree, 2—disagree, 3—neutral, 4—agree, 5—strongly agree). In the reliability analysis, the Cronbach's alpha coefficient for the entire scale was calculated as 0.88, while the reliability coefficients for the subscales were 0.84, 0.78, 0.73, and 0.70, respectively. Both exploratory factor analysis [EFA] and

confirmatory factor analysis [CFA] were conducted to examine the construct validity of the scale. The results indicated that the scale is a valid and reliable instrument for assessing students' attitudes toward environmental issues. Sample items from the Attitude Toward Environmental Problems Scale are as follows:

1. The idea that toxic substances released into the environment affect all living beings does not frighten me.
2. I conduct research on how environmental problems can be solved.
3. I would like to volunteer in activities aimed at protecting the environment.

2.3.2. Environmental Awareness Scale in the Context of Sustainable Development

In this study, the Environmental Awareness Scale in the Context of Sustainable Development was used, as it is theoretically well grounded, has a two-factor structure that addresses environmental awareness from multiple dimensions, and was specifically developed to be appropriate for the middle school level. This scale enabled a comprehensive assessment of students' attitudes toward environmental problems and their level of environmental awareness within the framework of sustainable development. This scale was developed by Atabek-Yiğit and Balkan Kıyıcı [121]. The scale development process began with the creation of an item pool and continued with item analysis, as well as validity and reliability studies. As a result, a measurement tool consisting of 16 items under 2 factors was developed. The scale consists of two factors: positive environmental awareness and negative environmental awareness. The items are structured using a 4-point Likert scale (strongly disagree, disagree, agree, strongly agree). In the reliability analysis, the Cronbach's alpha coefficient for the entire scale was calculated as 0.833, while the reliability coefficients for the sub-dimensions were 0.803 and 0.760, respectively. Both exploratory and confirmatory factor analyses were performed to examine construct validity, and the findings confirmed that the scale is both valid and reliable. Sample items from the Environmental Awareness Scale in the Context of Sustainable Development are as follows:

1. Using a recycled product makes me happy.
2. I use a product I use over and over again for different purposes.
3. Instead of buying water in a plastic bottle, I carry my water bottle with me.

2.4. Procedures

The present study commenced following the acquisition of ethical approval from the university's ethics committee, implementation authorization from the Provincial Directorate of National Education, and the necessary permissions from the participating schools. At the beginning of the study process, meetings were held with the teachers working in the implementation classes to inform them about the scope and procedures of the research. Since the presence of the teachers in the classroom during the implementation was required, the researcher also introduced the AR application to the teachers and provided a hands-on demonstration of how the technology would be used during the reading activities. This approach aimed to facilitate effective communication between teachers and students and to help students feel more comfortable throughout the implementation process. Nevertheless, the implementation was conducted directly by the researcher.

During the data collection phase, the scales were first administered to participants in both the experimental and control groups. The scores obtained from the Attitude Toward Environmental Problems Scale and the Environmental Awareness Scale in the Context of Sustainable Development were considered pre-test data. Subsequently, a four-week instructional intervention was carried out. During this process, the control group engaged in traditional reading activities involving texts related to the environment and sustainability,

with one text covered each week. The experimental group, on the other hand, participated in the same reading activities using AR-supported versions of the texts in the same order.

The tablets used in the AR-supported reading activities were provided by the researcher, and all students were given identical tablet models to ensure consistency. These reading sessions were conducted during students' native language instruction classes under the supervision of their classroom teachers. At the end of the four-week intervention, the same scales were re-administered to the participants as post-tests. Students were informed that these tests were not examinations, and they were encouraged to respond to the questions freely, sincerely, and comfortably during both the pre-test and post-test phases. Following the completion of these stages, the data analysis phase of this study was initiated.

2.5. Data Analysis

The data were analyzed using the SPSS 26.0 statistical software. An appropriate statistical software package was used for data analysis. Initially, the normality of the data distribution was examined. The results indicated that the data were normally distributed. To determine whether there was a statistically significant difference between the two groups in the pre-test scores, an independent samples *t*-test was conducted. Similarly, an independent samples *t*-test was used to analyze the post-test data to compare the two groups. For within-group comparisons, paired samples *t*-tests were employed. Furthermore, in cases where significant differences were observed in the post-test phase, Cohen's d was calculated to determine the effect size of the observed differences.

3. Results

This section presents the findings based on the quantitative data of this study. The findings are organized under two main categories: within-group comparison results and between-group comparison results. Additionally, the analysis results are briefly presented in a way that addresses the relevant research questions.

3.1. Within-Group Comparisons: Pre-Test and Post-Test Results

This section presents the within-group pre-test and post-test findings regarding students' attitudes toward environmental problems and their levels of environmental awareness in the context of sustainable development. Table 2 presents the means, standard deviations, and within-group analysis results for both the experimental and control groups in the pre-test and post-test phases.

Table 2. Pre- and post-test means and standard deviations for retelling.

			Pre-Test		**Post-Test**		
	Group	**N**	**Mean**	**Sd**	**Mean**	**Sd**	**t**
Attitude Towards Environmental Problems	Experiment	73	93.301	9.591	99.232	6.270	−8.272 *
	Control	74	91.945	8.645	94.743	8.006	−6.749 *
Environmental Awareness on the basis of Sustainability	Experiment	73	51.452	6.599	57.068	4.882	−12.985 *
	Control	74	50.702	7.835	53.891	7.019	−11.700 *

* $p < 0.05$.

An examination of within-group comparisons revealed that the students who participated in the traditional text-based reading activities on environmental and sustainability topics exhibited a statistically significant increase in their scores on the Attitude Toward Environmental Problems Scale ($t = -6.749$, $p < 0.05$). Similarly, the pre-test and post-

test comparison of students in the control group showed a significant improvement in their Environmental Awareness scores within the context of sustainable development ($t = -11.700$, $p < 0.05$).

Students who participated in the AR-supported reading activities on environmental and sustainability topics also showed a significant increase in their attitude scores toward environmental problems ($t = -8.272$, $p < 0.05$). The results further indicated that the magnitude of score improvement in the experimental group was greater than that observed in the control group. Likewise, a significant improvement was found in the students' environmental awareness scores in the context of sustainable development following the AR intervention ($t = -12.985$, $p < 0.05$).

3.2. Between-Group Comparisons: Pre-Test and Post-Test Results

In this study, the pre-test and post-test levels of students' attitudes toward environmental problems and their environmental awareness in the context of sustainable development were compared between the experimental and control groups using an independent samples *t*-test. The results reveal the statistical significance and effect size of the differences between the groups before and after the intervention. Table 3 presents the analysis findings related to the pre-test results.

Table 3. Results of the independent groups *t*-test for the pre-test.

	Group	**t**	***p***
Attitude Towards Environmental Problems	Experimental Group and Control Group	0.900	0.369
Environmental Awareness of the Basis of Sustainability	Experimental Group and Control Group	0.627	0.532

During the pre-test phase of this study, data were collected from both the experimental and control groups using two separate scales in order to determine their levels of attitude toward environmental problems and environmental awareness in the context of sustainable development. The collected data were then analyzed. The results indicated that, in the absence of any intervention, there was no statistically significant difference between the experimental and control groups in terms of their attitudes toward environmental problems ($t = 0.900$, $p > 0.05$) or their levels of environmental awareness in the context of sustainable development ($t = 0.627$, $p > 0.05$). The post-test results for both groups are presented in Table 4.

Table 4. Results of the independent groups *t*-test for the post-test.

	Group	**t**	***p***	**Cohen d**
Attitude Towards Environmental Problems	Experimental Group and Control Group	3.781	0.000	0.624
Environmental Awareness of the Basis of Sustainability	Experimental Group and Control Group	3.189	0.002	0.525

The post-test results of this study revealed a statistically significant difference in favor of the experimental group between the attitude scores toward environmental problems of students who participated in the AR-supported reading activities and those who took part in the traditional reading activities ($t = 3.781$, $p < 0.05$). Similarly, the post-test results showed a significant difference in environmental awareness levels within the context of sustainable development between the two groups, again in favor of the experimental group ($t = 3.189$, $p < 0.05$).

In addition, effect sizes were calculated for the post-test results. Cohen's d values for the domains of attitude toward environmental problems and environmental awareness in

the context of sustainable development were 0.624 and 0.525, respectively. These values indicate a medium effect size for both constructs.

3.3. Answers to the Research Questions

Based on the findings presented above, the research questions can be answered as follows:

RQ1: The results of the reading activity implemented through AR texts on environmental and sustainability topics significantly improved students' attitudes toward environmental problems when compared to the traditional reading activity. A statistically significant difference was observed in favor of the experimental group. However, the within-group pre-test and post-test evaluations revealed that the traditional reading activity also led to a significant difference in the control group's attitude scores toward environmental problems.

RQ2: The results of the reading activity implemented through AR texts on environmental and sustainability topics significantly enhanced students' environmental awareness in the context of sustainable development compared to the traditional reading activity. A statistically significant difference was observed in favor of the experimental group. However, the within-group pre-test and post-test evaluations showed that the traditional reading activity also resulted in a significant difference in the control group's environmental awareness scores in the context of sustainable development.

4. Discussion

The aim of this study was to examine the effect of AR-supported texts on students' attitudes toward environmental problems and their environmental awareness in the context of sustainable development. In order to observe the impact more clearly, a control group was also included in this study, and a pre-test was administered to both groups. There was no significant difference between the groups at the outset. While the experimental group engaged with AR-supported texts, the control group participated in traditional text reading activities. The results indicated that augmented reality applications have significant potential for use in environmental education. Similar findings in the literature demonstrate that such applications enhance students' understanding of environmental topics and support more effective knowledge construction during the learning process [42,45,122,123]. Indeed, existing research supports this claim, indicating that AR-supported learning enhances student interest, enriches personalized and interactive learning environments, and improves comprehension [55,57,124–127]. These studies are consistent with the present findings. Prior research on AR also emphasizes its ability to transform learning into an immersive, multimodal experience that engages multiple senses—thus moving beyond text-based instruction [128–132].

Many studies further indicate that AR applications attract children's attention, provide enjoyable and realistic learning experiences [66,124,133,134], enhance motivation and learning outcomes [61,62], and support easier acquisition of abstract concepts by reducing learning difficulties [135,136]. Positive effects on learning attitudes and academic achievement have also been reported [123,137,138].

In this way, it can be suggested that students were able to construct clearer mental representations of the content related to environmental education, which in turn contributed to a significant increase in their attitudes and awareness levels toward the environment.

This study contributes to the environmental education literature in terms of both instructional settings and technology integration. Most previous studies on the use of AR for raising awareness of environmental issues have implemented this technology to enrich applications that require interaction with nature [35,139–142]. In an exemplary study,

Eames & Aguayo [143] aimed to enhance students' and parents' marine ecological literacy by integrating mobile learning tools (smart devices, AR/VR) into marine ecology excursions (Goat Island Marine Reserve and Discovery Centre). The research found that these field trips, supported by augmented reality and mobile technologies, strengthened students' environmentally friendly behaviors (e.g., attitudinal change toward plastic pollution) and increased their learning motivation.

In the study conducted by Lo, Lai, and Hsu [144], it was found that augmented reality (AR)-supported science applications positively contributed to students' learning processes about plants, increased their interest in the environment, and facilitated deeper conceptual learning. It can be stated that AR activities conducted outside the classroom can be effectively utilized in environmental education. However, not all geographical conditions are safe for children and educational settings, and such activities may not always be efficient in terms of time and cost. Therefore, studies that exemplify the effective use of AR in classroom-based environmental education are gaining importance. In the present study, AR technology was applied directly in the classroom through AR-supported storybooks. As such, a systematic example was provided to promote students' attitudes toward environmental problems and their environmental awareness within the context of sustainable development in a school setting. However, these results should be interpreted with caution. As emphasized by Kollmuss and Agyeman [88], although many individuals are aware of environmental problems, this awareness does not often translate into concrete behavioral change. The researchers stated that, due to the multitude of complex variables influencing behavior, an increase in awareness alone may not be sufficient to drive individuals toward environmental action.

The findings of the present study are also consistent with those of other studies in which AR was used in environmental education. Previous research has shown that the integration of digital technologies, including AR, into environmental education can enrich the instructional process; however, it has also emphasized the need for more robust, systematic, and descriptive studies to better understand the concrete effects of these technologies on learning [145]. Moreover, these studies have revealed that such applications have a positive impact on students' interest, motivation, and learning outcomes in the context of environmental education [131]. Similarly, Wang et al. [47] reported that an AR-based game significantly enhanced participants' knowledge of sustainability and climate change. In a related study by Czok, Krug, Müller, Huwer, and Weitzel [146], AR-based game learning environments were compared with other methods in the context of sustainable development education. While AR produced a relatively higher cognitive load, it did not negatively affect learning outcomes and was found to enhance motivation and user engagement. These findings support the conclusion that AR technology is effective in fostering positive attitudes toward environmental issues, aligning with similar studies in the literature.

Based on the research findings, students who engaged with AR-supported reading activities demonstrated a significantly greater improvement in their scores compared to those who participated in traditional reading activities. In particular, a marked increase was observed in both environmental awareness and attitudes toward environmental problems following the AR intervention. For instance, in a study by Chen, examining the use of AR-supported digital picture books in environmental education among children from diverse cultural backgrounds, AR content was shown to improve environmental attitudes effectively through visual information but did not have a direct effect on environmental behaviors.

Moreover, Lee & Yoon [78] found that AR-based reading activities enhanced children's empathy toward environmental problems and allowed them to personalize their learning experiences. Arici [77] highlighted the significant contributions of AR to environmental

knowledge, skills, and sensitivity, as well as to the development of students' self-regulation abilities. In this context, AR can be considered a powerful tool for facilitating student understanding of environmental concepts and fostering sustainability awareness. These findings are consistent with the present study. However, more research is needed to optimize the use of AR technology in educational contexts [72,73].

Since most environmental concepts involve processes that students cannot directly experience in their daily lives, it can be challenging to foster interest and motivation toward these topics. At this point, AR-supported content enhances the learning experience by providing students with visual, auditory, and interactive elements, making the process more engaging and attention-grabbing, and thus facilitating a better understanding of environmental issues [147–149]. Furthermore, the limited number of studies in the field of environmental education targeting middle school students adds to the originality of this research. In this respect, the present study presents noteworthy findings by demonstrating that AR-supported storybooks particularly contribute to the development of students' attitudes toward environmental problems.

5. Conclusions and Limitations

This study aimed to examine the impact of AR-supported texts on students' attitudes toward environmental problems and their environmental awareness within the context of sustainable development. In this context, texts addressing issues related to environmental problems and sustainability were initially identified and then developed into AR storybooks. While previous research in the literature has predominantly focused on the effects of AR storybooks in terms of reading comprehension, this study offers a novel contribution by applying AR storybooks in the context of environmental and sustainability education, thereby presenting noteworthy findings.

Accordingly, this study provides evidence that AR technology offers students an engaging, concrete, comprehensible, and effective learning experience, particularly on environmental and sustainability-related topics that are often difficult to experience directly in a traditional classroom setting. In this regard, the study demonstrates the potential of AR to positively influence students' attitudes toward environmental issues. Moreover, the limited number of studies on this topic conducted with secondary school students highlights the contribution of the current findings to the existing literature.

The current study has some limitations. Firstly, it was conducted with participants aged 11–12. Therefore, the data are limited to this age group. Therefore, including participants from different age groups in future studies may provide important contributions by helping to determine the effect of age as a variable on the results and by enhancing the generalizability of the findings. In this research, several texts addressing environmental and sustainability issues were used. To reduce the influence of individual texts on the results, more than one text was selected. However, conducting new studies with different texts would further support the generalizability of the findings. Similarly, the digital elements used in the creation of AR storybooks may also have influenced the results. Therefore, future studies could utilize AR storybooks enriched with interactive options and 3D content. In addition, for visually impaired individuals who wish to interact with AR content on environmental topics, materials produced using 3D printers can be developed, and AR content can be integrated into these materials through QR code-like triggers. Additionally, this study aimed to positively influence students' attitudes and awareness regarding environmental and sustainability concepts within a classroom setting. The results provided evidence for the usability of the current technology in the classroom environment. Moreover, the emergence of AR as an effective learning tool in environmental education necessitates a discussion on how it can be integrated with traditional pedagogical

approaches. When combined with hands-on instructional methods such as experiential fieldwork, AR technology can enrich real-life contexts and contribute to the concretization of abstract environmental concepts. In this context, how AR can be synchronized with traditional methods, its contribution to the learning process, and its role in both in-class and out-of-class applications should be examined in detail.

Future studies may focus on examining the effects of similar interventions in different settings. Finally, in the present study, AR applications were utilized in environmental education, and data were obtained supporting the use of digital technologies in this field. Based on these findings, it is recommended that future research investigate the potential effects of emerging digital technologies—such as virtual reality and artificial intelligence—on individuals' environmental education processes.

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Abbreviation

The following abbreviation is used in this manuscript:

AR augmented reality

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