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Effectiveness of Fine Dust Environmental Education on Students' Awareness and Attitudes in Korea and Australia Using AR Technology

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Abstract: This study evaluated the influence of fine dust environmental education on 90 elementary and middle school students, taking into account factors such as sex, place of residence, experience with environmental education, and experience with augmented reality (AR). The goal was to assess changes in students' awareness and attitudes towards fine dust. Results showed that fine dust environmental education positively influenced students' awareness of fine dust. Further analysis by factors revealed that the education was effective regardless of these factors. In addition to increasing awareness of the seriousness of fine dust, students' attitudes also changed positively. The study conducted a statistical analysis of changes in 10 types of attitudes among the target students before and after our education. After the implementation of the education, students' attitudes changed positively in all 10 types of attitudes, including checking the weather, restricting activities, personal hygiene, wearing masks, environmental education, separating garbage and cleaning, classroom silence, classroom ventilation, home cleaning, and home environment with statistical significance. These findings underscore the effectiveness and importance of combining fine-dust environmental education with AR technology and can inform the planning of educational programs aimed at improving students' awareness and attitudes.

Keywords: fine dust; environmental education; educational effect; awareness; attitude; augmented reality; change

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1. Introduction

Particulate matter (PM) is a complex mixture of microscopic particles and liquid droplets that have significant effects on human health and the environment. PM10 and PM2.5 particles, with aerodynamic diameters less than 10 µm and 2.5 µm, respectively, are of particular concern due to their ability to penetrate the respiratory tract and enter the human body, causing various health problems. According to data from the World Health Organization (WHO), over 90% of the global population is exposed to air pollution levels exceeding air quality guidelines, with wide regional variations in concentrations. The global average annual concentration of PM2.5 is 23 $\mu g/m^3$, while that of PM10 is 41 $\mu g/m^3$ [1,2]. Industrial activity, transportation, and agricultural incineration are among the main causes of air pollution.

PM10 and PM2.5 can reach deep into the lungs, while PM2.5 can enter the bloodstream, negatively affecting the cardiovascular and respiratory systems as well as other organs. It is estimated that air pollution causes 7 million premature deaths annually, with millions more suffering from respiratory and cardiovascular diseases [3]. Numerous studies have examined the effects of PM10 and PM2.5 on human health, linking exposure to an increased risk of respiratory diseases, death, increased hospitalizations, and decreased respiratory function due to cardiovascular and respiratory disorders [4,5]. In 2016, air pollution was estimated to have caused 4.1 million premature deaths worldwide [6]. The premature deaths are attributed to strokes, heart disease, lung cancer, and chronic obstructive pulmonary disease (COPD) [7].

The issue of particulate matter (PM) in the atmosphere is becoming increasingly pronounced as industries advance, leading to a decrease in PM particle sizes and an increase in the concentration of fine particles. This is particularly evident in Korea. The air quality issue in Korea re-emerged in the mid-2010s, following the air quality problems experienced during the economic boom of the 1980s and 1990s. As the concentration of air pollutants, such as fine dust (particles smaller than PM10), continued to rise from the late 2010s, it emerged as a serious air quality problem. In Seoul, for example, PM2.5 concentrations averaged 37 $\mu g/m^3$ in 2012 and 2013, with relatively high concentrations in summer and winter [8]. About 60% of PM2.5 concentrations in January and February and 20% in August originated from China due to emissions from transportation and industry [9,10]. From 2015 to 2021, it exceeded the World Health Organization's (WHO) highest level, 10 $\mu g/m^3$, that does not pose a risk to human health [11].

On the other hand, Australia enjoys relatively good air quality compared to Korea, owing to its expansive land area and low population density. However, efforts are required to enhance air quality in urban areas. In recent times, air pollution stemming from wildfires, exacerbated by climate change, has emerged as an increasingly significant issue. Australia's air quality in 2022 was generally considered relatively good compared to many other countries [12]. However, bushfires in Queensland and New South Wales in September 2019 increased PM2.5 concentrations, reaching 98.5 $\mu g/m^3$, leaving no safe zone for fine dust [13]. According to Australia's National Environment Protection Measure (NEPM), the annual and daily average concentrations of PM10 should not exceed 25 $\mu g/m^3$ and 50 $\mu g/m^3$, respectively. The average daily concentration of PM2.5 should not exceed 25 $\mu g/m^3$, with an annual average concentration not exceeding 8 $\mu g/m^3$ [14].

These findings highlight the urgent need for both countries to address the issue of particulate matter pollution. While the specific challenges and contexts may differ, the ultimate goal remains the same: reducing the concentration of harmful particulate matter in the atmosphere.

Under circumstances similar to those in Australia and Korea, expecting a short-term improvement in the status of fine dust solely through reliance on national and international policies will be challenging. Assuming that the current situation persists, individual measures to respond to fine dust must be prepared. Among these, inducing behavioral changes through improved awareness, particularly through environmental education, is deemed essential.

Environmental education has been shown to be effective in strengthening individuals' knowledge, awareness, and responsibility for environmental issues and increasing environmental protection behaviors [15]. Through environmental education, students demonstrate significant improvements in critical thinking skills and changes in attitudes towards the environment [16], which can play a large role in helping students gain a deeper understanding of the environmental and social factors contributing to environmental pollution and develop more effective strategies for reducing pollution.

The objective of this research is to create an augmented reality (AR)-based educational program focusing on fine dust, and to investigate whether this program leads to positive changes in awareness and attitudes towards fine dust. The study examines the impact of fine dust environmental education across different categories among elementary, middle, and high school students in both Korea, where fine dust is a significant issue, and Australia, where it is not. The research assesses the effectiveness of education and information dissemination related to fine dust, personal practices such as hygiene and mask-wearing, and environmental strategies like classroom and home ventilation and cleaning as a means of coping. This also demonstrates that enhancing awareness by education about fine dust significantly influences students' attitudes and behaviors in their daily lives.

2. Materials and Methods

2.1. Background

This study employed AR technology in environmental education to maximize the educational effect on students' awareness and attitude toward fine dust. Augmented reality (AR) is a technology that allows individuals to interact with the real world by overlaying digital content with information from the real world. AR provides a way to enhance ecological education by offering an experiential learning environment. Visualizing content through AR enables students to directly observe and discover ecological systems through experience, as well as immediately access ecological system information to deepen their understanding and sensory experience of the ecological environment. This allows for learning progress through self-discovery and exploration [17].

Outdoor environmental education using augmented reality offers several advantages, including active participation and hands-on experience for students, enhancements in problem-solving skills and creative thinking, and positive impacts on learning outcomes and inquiry skills [18,19]. Compared to traditional learning methods, AR-based learning methods are also effective in improving students' learning attitudes. AR-based learning environments have been shown to be more effective in improving student motivation and engagement than textbook-based methods in biology learning [20]. In mathematics education, the use of AR can help students visually explore and understand mathematical concepts and relationships, promoting self-active participation and interaction in the learning process [21]. The visual richness, experience, interaction, and content adaptation to the specific needs of learners are all advantages of AR-based education. However, technical limitations, the complexity of content development, customized content composition according to the diversity of user experience, and consistency of content are disadvantages [22]. These findings suggest that AR-based teaching methods may be effective in improving students' awareness and attitudes towards a variety of teaching topics [23]. Because fine dust is harmful to the human body and should not be directly experienced, AR technology can be an alternative to provide a safe environment for experiential learning without exposure to fine dust. In fact, a study of 182 high school students using an AR fine dust education simulator showed that AR-based environmental education on fine dust increased student participation in class compared to traditional teaching methods, increased their interest in fine dust, and caused significant changes in their awareness and attitude towards fine dust after learning [24]. AR has been shown to have a positive influence on integrating into mobile learning environments, providing an interesting learning experience, and improving the visual representation and interaction of learning content. This makes it an effective tool for increasing students' motivation and engagement in learning [25].

2.2. Materials

A total of 90 elementary school students from Korea and Australia participated in a 2 h fine-dust environmental education program as an extracurricular activity over the course of 2 days (Figure 1). We decided to target the entire class of a school or institution at random because setting selection criteria could result in characteristics that deviate from those of typical students. For Korean students, we targeted all students in one elementary school class, and for Australian students, we targeted all students in a class taking Korean lessons.

On the first day, students conducted a survey before the class. Then, they were introduced to the basic concepts of fine dust, its causes, and its dangers to the human body through a combination of lectures and discussions. On the second day, instruction was conducted in two stages using augmented reality (AR). In the first stage, students were introduced to the AR application and shown examples of moving pictures in newspapers and wall bulletins, similar to those in the Harry Potter movies. Students were able to register their own photos or texts as markers, and when a marker was recognized by the camera, an animated character singing in three dimensions was displayed on the screen.

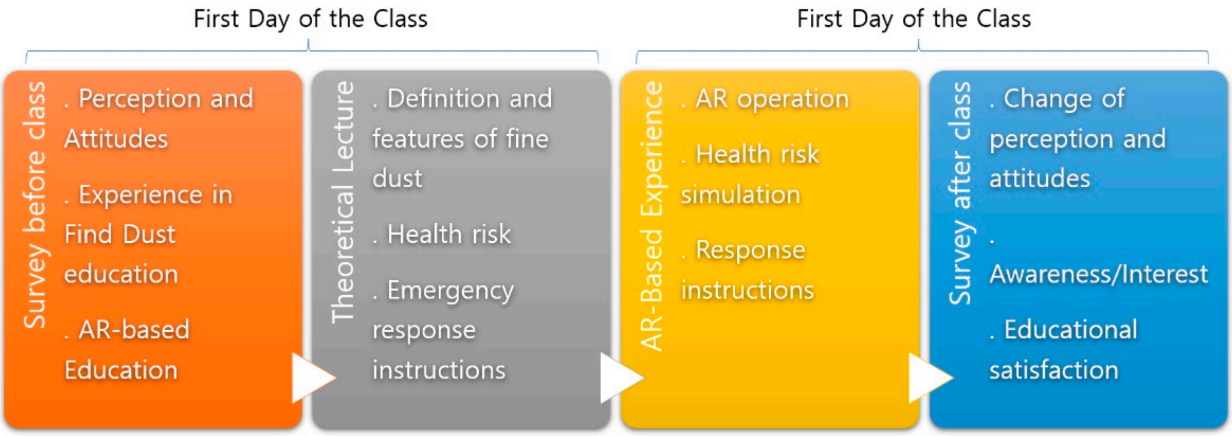

Figure 1. Steps of the survey and fine dust environmental education.

In the second stage (Figure 2), students learned about the process of fine dust entering the human body, its path and danger to each organ, the time it takes for fine dust to be introduced and expelled from the body, and the principle of removing fine dust using artificial rainfall. Each topic was presented through a short video, with thumbnail images registered as markers in advance. When the camera recognized a marker, the video was superimposed on the image via the display screen. Additionally, when students used the camera to view themselves, an image of their lungs was superimposed on their image to provide interest. QR codes were used to quiz students on their understanding of what they had learned in the first session, and various learning materials were used to experience air quality index according to air quality concentration in urban situations. Finally, prepared questionnaires using Likert measures from 1 (not agreed at all) to 5 (strongly agreed) were distributed to students to evaluate the awareness and attitude on the fine dust education using AR.

The variables of the questionnaires were sex, residence area, experience with fine dust education, experience with AR use according to sample characteristics, and awareness of the seriousness of fine dust. To compare the effectiveness of education, the pre- and post-survey questionnaires were comprised of questions regarding the awareness of the seriousness of fine dust and 10 attitudes towards fine dust. These items were analyzed based on the characteristics of the sample. The overall reliability of the 10 questions related to attitude was assessed using Cronbach's α, yielding a value of 0.802 for the pre-test and 0.861 for the post-test. Since the reliability of each question was below 0.6, we decided not to calculate the average by individual question. The 10 questions related to attitude were as follows:

① Check weather conditions through broadcasting, the internet, etc.
② Close windows and avoid outdoor activities when fine dust levels are high.
③ Maintain personal hygiene, such as washing hands and brushing teeth thoroughly.
④ Wear a mask when going to and from school during heavy fine dust conditions.
⑤ Participate in environmental education such as fine dust when an opportunity arises.
⑥ Separate and recycle waste properly, and thoroughly clean the surroundings.
⑦ Do not run or engage in rough play in the classroom.
⑧ Ventilate indoor air after a fine dust warning has ended.
⑨ Clean and organize whenever you have a chance.
⑩ Ventilate indoor air regularly every day when there is no fine dust warning outdoors.

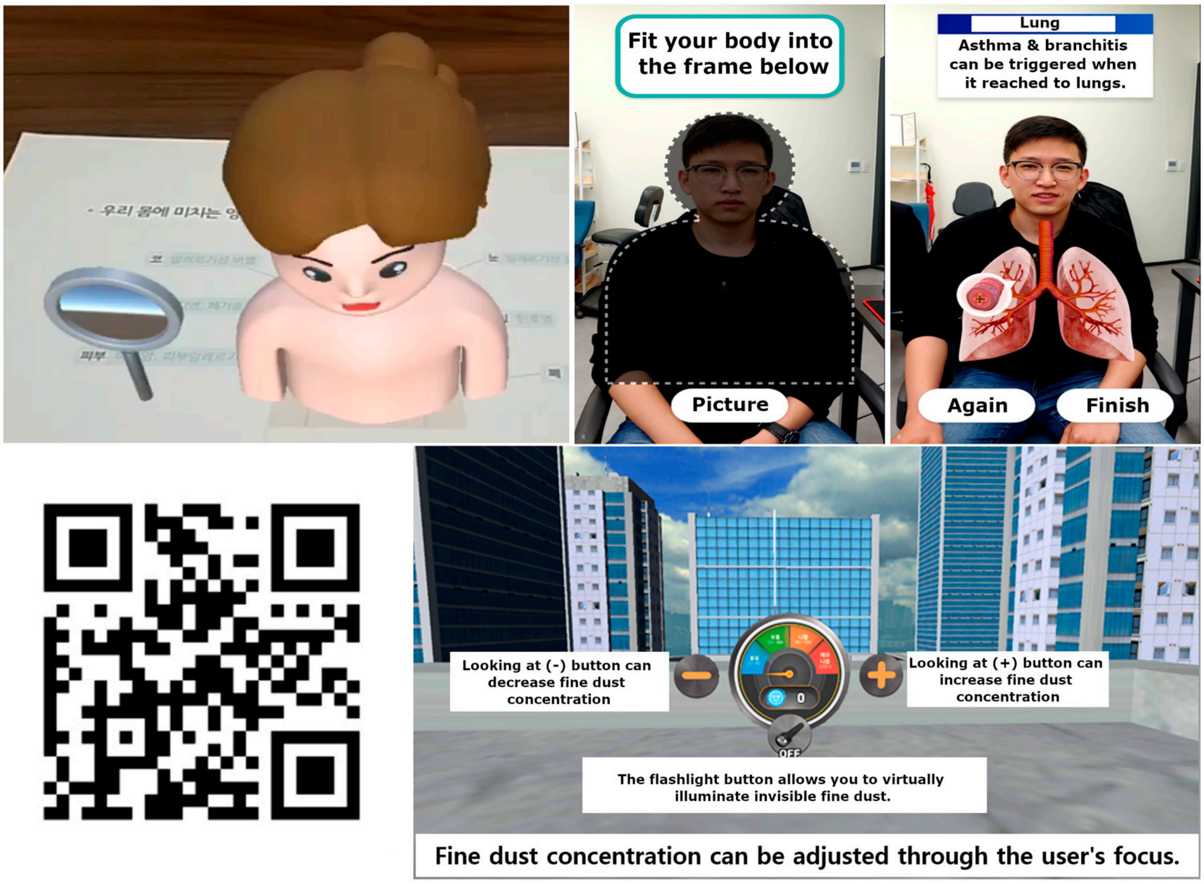

Figure 2. Pictures in the second stage during the AR-based environmental education.

2.3. Methods

The collected questionnaires were evaluated using a paired *t*-test, which compares the mean of the post-test to the mean of the pre-test. If the education was found to be effective, the effect size was calculated to determine the magnitude of the effect. Effect size is an objective and standardized measure of the observed data. The Cohen's *d* value calculated as the measure of effect size using Equation (1) as proposed by (Cohen, 1988) [26] was employed when the pre- and post-test number of a group was the same, where *t* is the result of the *t*-test, *n* is the sample size, and *s* is the standard deviation.

$$Cohen's\ d = \frac{t}{\sqrt{n}} \quad (1)$$

A large effect size (e.g., 0.8 and above) represents a substantial impact on students' attitudes and behaviors. This is likely to be practically significant and may have important real-world consequences, indicating a major shift or change. A medium effect size (e.g., 0.5) suggests a moderate impact on students' attitudes and behaviors. This is often considered meaningful as it indicates a noticeable change or difference. A small effect size (e.g., 0.2) indicates a small, but detectable, effect on students' attitudes and behaviors. In practical terms, this suggests a limited impact that may have some relevance but might not be of significant importance.

3. Results

Investigating the impact of environmental education and augmented reality (AR) on elementary and junior high school students, a total of 90 participants took part in the study. The participant demographics included 52 females and 38 males. Geographically, 44 students were from Korea, and 46 were from Australia. Among the participants, 40 reported prior exposure to environmental education, while 50 had no prior experience in this domain. Furthermore, 24 students had prior exposure to AR, while 66 had no previous experience with this technology.

3.1. Effectiveness on Awareness of Severity of Fine Dust

Increasing students' awareness of fine dust, the fine dust environmental education with AR technology demonstrated significant improvement. Table 1 presents the results of the questionnaire assessing awareness of fine dust severity.

Table 1. Awareness of severity of fine dust.

Category		Freq.	Post-Test (A)		Pre-Test (B)		GAP	t	Effect Size
			Mean	Std.	Mean	Std.	(A–B)		
Overall		90	3.48	0.738	2.74	0.966	0.74	7.356 ***	0.775
Sex	Female	52	3.40	0.799	2.73	0.952	0.67	5.142 **	0.713
	Male	38	3.58	0.642	2.76	0.998	0.82	5.269 **	0.855
Location	Korea	44	3.68	0.561	2.91	0.884	0.77	6.383 ***	0.962
	Australia	46	3.28	0.834	2.59	1.024	0.69	4.400 ***	0.649
Env. Edu. Experience	Yes	40	3.50	0.679	2.85	0.893	0.65	4.759 **	0.752
	No	50	3.46	0.788	2.66	1.022	0.80	5.600 ***	0.792
AR Usage Experience	Yes	24	3.46	0.721	2.83	1.049	0.63	3.315 **	0.677
	No	66	3.49	0.749	2.71	0.941	0.78	6.556 ***	0.807
Awareness	Low	52	3.60	0.664	2.65	0.926	0.95	7.415 ***	1.028
	High	38	3.32	0.809	2.87	1.018	0.45	2.994 **	0.486

Note: ** $p < 0.01$, *** $p < 0.001$.

Overall awareness increased significantly from the pre-test to the post-test (t = 7.356, $p < 0.001$), with an effect size of 0.775, indicating a medium level of effectiveness. Both male and female students exhibited higher average scores after environmental education compared to before, with a statistically significant difference ($p < 0.001$). The effect size was medium for females (0.713) and large for males (0.855), affirming the effectiveness of the education for both genders.

When analyzing by the region of residence, students in both Korea and Australia showed statistical significance ($p < 0.001$) with a large (0.962) to medium (0.649) effect size, respectively. Regardless of prior experience with environmental education, all groups demonstrated significant differences ($p < 0.01$ for Yes and $p < 0.001$ for No) with a large effect size of 0.752 or greater, signifying improved awareness. Likewise, concerning experience with AR, a statistically significant difference ($p < 0.01$ for Yes and $p < 0.001$ for No) was observed regardless of prior exposure, with medium (0.677) to large (0.807) effect sizes, indicating improved awareness. The level of awareness also had a positive influence on both low and high levels of students' awareness. Those who have a high level of awareness of fine dust showed a medium effect size (0.486); it is still statistically significant ($p < 0.01$). Both low and high levels of awareness showed statistical significance. Notably, the effect size was relatively higher among students with no prior experience with AR.

3.2. Effectiveness of Attitude Changes

Figure 3 presents the results of a statistical analysis of changes in students' attitudes towards 10 items, measured before and after the implementation of fine-dust environmental education. Overall, students' attitudes towards the items changed positively after the implementation of fine-dust environmental education. The overall average increased from 2.75 before environmental education to 3.38 afterwards, representing a statistically significant difference ($p < 0.001$). The improvements were shown in all items, including "weather check", "activity restraint", "personal hygiene", "wearing masks", "environmental education", "waste separation and cleaning", "silence", "ventilation", "home cleaning", and "home environment". All of the items showed statistically significant results with $p < 0.001$.

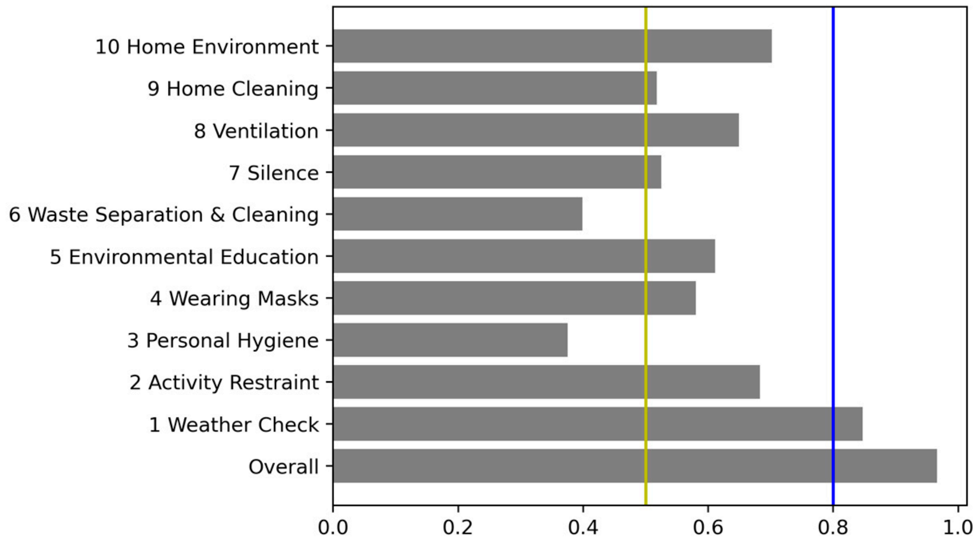

Figure 3. Effect sizes of attitudes for all respondents (values above blue and yellow lines indicate a high and medium level of effect size, respectively).

Table 2 summarizes the pre- and post-survey results of changes for all respondents by characteristic groups. When analyzed by sex, the average changes for female and male were 0.6 and 0.67, respectively, with a statistically significant difference ($p < 0.001$). The effect sizes were above 0.9, indicating that the attitudes improved after environmental education regardless of sex. Additionally, there were statistically significant differences between students who had received environmental education and those who had not, as well as between students who had experience using AR and those who had not. In both cases, the effect size was large, indicating that their attitude changed regardless of prior experience with environmental education or AR. Students' awareness of the severity of fine dust was also effective, with an effective size greater than 0.9. They are all statistically significant ($p < 0.001$).

Table 2. Changes of attitudes for all respondents by characteristic groups.

Category		Freq.	Post-Test (A)		Pre-Test (B)		GAP (A–B)	t	Effect Size
			Mean	Std.	Mean	Std.			
Sex	Female	52	3.34	0.505	2.74	0.547	0.60	6.627 ***	0.919
	Male	38	3.43	0.513	2.76	0.603	0.67	6.291 ***	1.021
Location	Korea	44	3.53	0.404	2.85	0.567	0.68	6.238 ***	0.940
	Australia	46	3.24	0.557	2.66	0.559	0.58	6.816 ***	1.005
Env. Edu. Experience	Yes	40	3.38	0.526	2.80	0.522	0.59	5.619 ***	0.888
	No	50	3.38	0.498	2.71	0.605	0.66	7.230 ***	1.023
AR Usage Experience	Yes	24	3.38	0.573	2.79	0.605	0.59	4.625 ***	0.944
	No	66	3.38	0.487	2.74	0.558	0.64	7.865 ***	0.968
Awareness	Low	38	3.28	0.548	2.66	0.612	0.63	5.571 ***	0.904
	High	52	3.45	0.469	2.82	0.529	0.63	7.277 ***	1.009

Note: *** $p < 0.001$.

3.3. Attitude Changes by Characteristic Group

The effects of fine-dust environmental education on each of the 10 attitudes listed in Section 3 were examined. The results are presented in Tables 2–7 with two attitudes grouped in each table. The second item is shown in parentheses.

Table 3. Effectiveness on attitude change: weather check (activity restraint).

Category		Freq.	Post-Test (A)		Pre-Test (B)		GAP (A–B)	t	Effect Size
			Mean	Std.	Mean	Std.			
Overall		90	3.28 (3.39)	0.862 (0.730)	2.28 (2.68)	0.960 (0.910)	1.00 (0.71)	8.037 *** (6.479 ***)	0.847 (0.683)
Sex	Female	52	3.19 (3.35)	0.841 (0.738)	2.15 (2.60)	0.894 (0.891)	1.04 (0.75)	6.395 *** (5.268 ***)	0.887 (0.731)
	Male	38	3.40 (3.45)	0.887 (0.724)	2.45 (2.79)	1.032 (0.935)	0.95 (0.66)	4.839 *** (3.782 ***)	0.785 (0.613)
Location	Korea	44	3.41 (3.57)	0.844 (0.587)	2.41 (2.82)	0.816 (0.786)	1.00 (0.75)	5.354 *** (5.019 ***)	0.807 (0.757)
	Australia	46	3.15 (3.22)	0.868 (0.814)	2.15 (2.54)	1.074 (1.005)	1.00 (0.67)	5.974 *** (4.168 ***)	0.881 (0.615)
Env. Edu. Experience	Yes	40	3.13 (3.38)	0.992 (0.740)	2.38 (2.65)	0.868 (0.864)	0.75 (0.73)	3.840 *** (4.318 ***)	0.607 (0.683)
	No	50	3.40 (3.40)	0.728 (0.728)	2.20 (2.70)	1.030 (0.953)	1.20 (0.70)	7.668 *** (4.782***)	1.084 (0.676)
AR Usage Experience	Yes	24	3.38 (3.46)	0.875 (0.721)	2.38 (2.92)	0.824 (1.018)	1.00 (0.54)	4.796 *** (2.716 *)	0.979 (0.554)
	No	66	3.24 (3.36)	0.860 (0.737)	2.24 (2.59)	1.009 (0.859)	1.00 (0.77)	6.550 *** (5.900 ***)	0.806 (0.726)
Awareness	Low	38	3.21 (3.34)	0.811 (0.669)	2.18 (2.66)	0.982 (0.847)	1.03 (0.68)	5.738 *** (4.150 ***)	0.931 (0.673)
	High	52	3.33 (3.42)	0.901 (0.776)	2.35 (2.69)	0.947 (0.961)	0.98 (0.73)	5.683 *** (4.932 ***)	0.788 (0.684)

Note: * $p < 0.05$, *** $p < 0.001$.

Table 4. Effectiveness on attitude change: personal hygiene (wearing masks).

Category		Freq.	Post-Test (A)		Pre-Test (B)		GAP (A–B)	t	Effect Size
			Mean	Std.	Mean	Std.			
Overall		90	3.68 (3.61)	0.577 (0.665)	3.37 (3.07)	0.800 (0.969)	0.31 (0.54)	3.557 *** (5.506 ***)	0.375 (0.580)
Sex	Female	52	3.71 (3.60)	0.498 (0.634)	3.40 (2.94)	0.748 (0.938)	0.31 (0.65)	2.939 ** (4.977 ***)	0.407 (0.690)
	Male	38	3.63 (3.63)	0.675 (0.714)	3.32 (3.24)	0.873 (0.998)	0.32 (0.40)	2.086 * (2.655 *)	0.338 (0.431)
Location	Korea	44	3.64 (3.68)	0.532 (0.347)	3.14 (3.43)	0.824 (0.759)	0.50 (0.43)	3.483 ** (3.280 **)	0.525 (0.494)
	Australia	46	3.72 (3.37)	0.621 (0.799)	3.59 (2.72)	0.717 (1.026)	0.13 (0.65)	1.354 (4.451 ***)	- (0.656)
Env. Edu. Experience	Yes	40	3.70 (3.75)	0.564 (0.543)	3.25 (3.10)	0.899 (0.928)	0.45 (0.65)	3.250 ** (4.215 ***)	0.514 (0.666)
	No	50	3.66 (3.50)	0.593 (0.735)	3.46 (3.04)	0.706 (1.009)	0.20 (0.46)	1.807 (3.581 ***)	- (0.506)
AR Usage Experience	Yes	24	3.58 (3.67)	0.776 (0.762)	3.38 (3.04)	0.970 (0.999)	0.21 (0.63)	1.045 (3.978 ***)	- (0.812)
	No	66	3.71 (3.59)	0.489 (0.656)	3.36 (3.08)	0.737 (0.966)	0.35 (0.52)	3.656 *** (4.202 ***)	0.450 (0.517)
Awareness	Low	38	3.53 (3.50)	0.725 (0.762)	3.29 (2.95)	0.898 (1.012)	0.24 (0.55)	1.781 (3.586 ***)	- (0.582)
	High	52	3.79 (3.69)	0.412 (0.579)	3.42 (3.15)	0.723 (0.937)	0.37 (0.54)	3.134 ** (4.137 ***)	0.435 (0.574)

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 5. Effectiveness on attitude change: environment education (waste separation and cleaning).

Category		Freq.	Post-Test (A)		Pre-Test (B)		GAP (A–B)	t	Effect Size
			Mean	Std.	Mean	Std.			
Overall		90	3.18 (3.34)	0.787 (0.752)	2.48 (2.94)	0.951 (0.916)	0.70 (0.40)	5.794 *** (3.782 ***)	0.611 (0.399)
Sex	Female	52	3.04 (3.29)	0.816 (0.776)	2.46 (3.00)	0.917 (0.816)	0.58 (0.29)	3.878 *** (2.389 *)	0.538 (0.331)
	Male	38	3.37 (3.42)	0.714 (0.722)	2.50 (2.78)	1.007 (1.044)	0.87 (0.55)	4.338 *** (2.948 **)	0.704 (0.478)
Location	Korea	44	3.48 (3.39)	0.505 (0.813)	2.68 (2.73)	0.959 (0.997)	0.80 (0.66)	4.746 *** (3.705 ***)	0.715 (0.558)
	Australia	46	2.89 (3.30)	0.900 (0.695)	2.28 (3.15)	0.911 (0.788)	0.61 (0.15)	3.490 ** (1.415)	0.515 (-)
Env. Edu. Experience	Yes	40	3.15 (3.30)	0.802 (0.723)	2.45 (3.00)	0.959 (0.877)	0.70 (0.30)	3.681 *** (2.020)	0.582 (-)
	No	50	3.20 (3.38)	0.782 (0.780)	2.50 (2.90)	0.953 (0.953)	0.70 (0.48)	4.455 *** (3.219 **)	0.630 (0.455)
AR Usage Experience	Yes	24	3.08 (3.33)	0.881 (0.702)	2.46 (2.96)	0.977 (0.999)	0.63 (0.38)	2.532 * (1.895)	0.517 (-)
	No	66	3.21 3.35	0.755 0.774	2.49 2.94	0.949 0.892	0.73 0.41	5.226 *** (3.250 **)	0.643 0.400
Awareness	Low	38	3.08 (3.29)	0.882 (0.732)	2.18 (2.92)	0.896 (0.941)	0.90 (0.37)	5.203 *** (2.217 *)	0.844 (0.360)
	High	52	3.25 (3.39)	0.711 (0.771)	2.69 (2.96)	0.940 (0.907)	0.56 (0.42)	3.365 ** (3.060 **)	0.467 (0.424)

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 6. Effectiveness on attitude change: silence (ventilation).

Category		Freq.	Post-Test (A)		Pre-Test (B)		GAP (A–B)	t	Effect Size
			Mean	Std.	Mean	Std.			
Overall		90	3.28 (3.40)	0.936 (0.667)	2.70 (2.73)	1.116 (0.909)	0.58 (0.67)	4.977 *** (6.154 ***)	0.525 (0.649)
Sex	Female	52	3.29 (3.35)	0.915 (0.711)	2.81 (2.75)	1.103 (0.905)	0.48 (0.60)	3.612 * (4.319 ***)	0.501 (0.599)
	Male	38	3.55 (3.47)	0.627 (0.603)	2.55 (2.71)	1.132 (0.927)	0.71 (0.76)	3.445 ** (4.371 ***)	0.559 (0.709)
Location	Korea	44	3.55 (3.52)	0.627 (0.590)	2.98 (2.84)	0.902 (0.861)	0.57 (0.68)	3.613 *** (4.494 ***)	0.545 (0.678)
	Australia	46	3.02 (3.28)	1.105 (0.720)	2.44 (2.63)	1.241 (0.951)	0.59 (0.65)	3.415 ** (4.178 ***)	0.504 (0.616)
Env. Edu. Experience	Yes	40	3.38 (3.45)	0.979 (0.714)	2.73 (2.90)	1.176 (0.810)	0.65 (0.55)	3.397 ** (3.626 **)	0.537 (0.573)
	No	50	3.20 (3.36)	0.904 (0.631)	2.68 (2.60)	1.077 (0.969)	0.52 (0.76)	3.623 ** (4.977 ***)	0.512 (0.704)
AR Usage Experience	Yes	24	3.17 (3.50)	1.049 (0.659)	2.58 (2.96)	1.213 (0.955)	0.58 (0.54)	2.290 * (2.600 *)	0.467 (0.531)
	No	66	3.32 (3.36)	0.897 (0.671)	2.74 (2.65)	1.086 (0.886)	0.58 (0.71)	4.441 ** (5.594 ***)	0.547 (0.689)
Awareness	Low	38	3.13 (3.32)	0.935 (0.662)	2.76 (2.66)	1.149 (0.938)	0.37 (0.66)	1.977 (3.782 ***)	- (0.613)
	High	52	3.39 (3.46)	0.932 (0.670)	2.65 (2.79)	1.101 (0.893)	0.73 (0.67)	5.019 ** (4.833 ***)	0.696 (0.670)

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 7. Effectiveness on attitude change: home cleaning (home environment).

Category		Freq.	Post-Test (A)		Pre-Test (B)		GAP (A–B)	t	Effect Size
			Mean	Std.	Mean	Std.			
Overall		90	3.31 (3.32)	0.802 (0.776)	2.71 (2.56)	0.939 (0.973)	0.60 (0.77)	4.910 *** (6.661 ***)	0.518 (0.702)
Sex	Female	52	3.33 (3.29)	0.810 (0.800)	2.71 (2.60)	0.893 (0.934)	0.62 (0.69)	3.628 *** (4.489 ***)	0.503 (0.623)
	Male	38	3.29 (3.37)	0.802 (0.751)	2.71 (2.50)	1.011 (1.033)	0.58 (0.87)	3.300 ** (5.004 ***)	0.535 (0.812)
Location	Korea	44	3.39 (3.50)	0.655 (0.629)	2.77 (2.71)	0.886 (0.930)	0.61 (0.80)	3.759 *** (4.659 ***)	0.567 (0.702)
	Australia	46	3.24 (3.15)	0.923 (0.868)	2.65 (2.41)	0.994 (1.002)	0.59 (0.74)	3.211 ** (4.715 ***)	0.473 (0.695)
Env. Edu. Experience	Yes	40	3.33 (3.28)	0.730 (0.784)	2.88 (2.65)	0.822 (1.027)	0.45 (0.63)	2.966 ** (3.748 ***)	0.469 (0.593)
	No	50	3.30 (3.36)	0.863 (0.776)	2.58 (2.48)	1.012 (0.931)	0.72 (0.88)	3.934 *** (5.564 ***)	0.556 (0.787)
AR Usage Experience	Yes	24	3.17 (3.38)	0.816 (0.875)	2.63 (2.38)	0.824 (0.824)	0.54 (1.00)	2.600 * (4.796 ***)	0.531 (0.979)
	No	66	3.36 (3.27)	0.797 (0.795)	2.74 (2.53)	0.982 (0.964)	0.62 (0.74)	4.163 *** (5.225 ***)	0.512 (0.643)
Awareness	Low	38	3.18 (3.26)	0.926 (0.795)	2.55 (2.42)	1.005 (1.081)	0.63 (0.84)	2.667 * (4.508 ***)	0.433 (0.731)
	High	52	3.40 (3.37)	0.693 (0.768)	2.83 (2.65)	0.879 (0.883)	0.58 (0.71)	4.657 *** (4.867 ***)	0.646 (0.675)

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

For "weather check" (Check weather conditions through broadcasting, the internet, etc.), the average score for all respondents increased from 2.28 before environmental education to 3.28 after environmental education. This change was statistically significant ($p < 0.001$) according to the *t*-test results, and the effect size was large at 0.847, indicating that students' attitudes towards weather checking improved significantly after fine-dust environmental education. Both male and female students showed a significant improvement in their attitudes, with a greater effect for females than for males. By region of residence, both Korea and Australia showed an improvement in attitude, with a similar effect size for both countries. This shows that the effect of fine dust environmental education was similar in both regions. In prior experience with environmental education, both students with and without prior experience showed an improvement in attitude, with a larger effect size for students without prior experience. Both students with and without AR experience showed a large effect size, indicating that their attitudes towards weather checking improved after fine dust environmental education. In terms of awareness of the severity of fine dust, it was found that both students with high and low awareness also showed an improvement in attitude, with a greater effect for students with high awareness of fine dust.

For "activity restraint" (Close windows and avoid outdoor activities when fine dust levels are high), it was found that students' attitudes towards refraining from activities improved significantly on average after fine-dust environmental education. The average attitude score increased by 0.71 after the education, which was a statistically significant difference. The effect size was 0.683, indicating a moderate effect and a positive change in attitude for all groups, regardless of sex, region of residence, and prior experience with environmental education. Students with experience using AR (augmented reality) showed a greater change in attitude than those who did not, with statistically significant differences at $p < 0.001$ and $p < 0.05$, respectively. It was also confirmed that students' awareness of the severity of fine dust had a moderate impact on their attitude change, regardless of their initial level of awareness.

For "personal hygiene" (Maintain personal hygiene, such as washing hands and brushing teeth thoroughly) there was a significant increase in attitudes towards personal hygiene in response to fine dust among all respondents. The average increased from 3.37 before environmental education to 3.68 after it, with an effect size of 0.375, which shows a small effect. When analyzed by sample characteristics, the educational effect was positive for both sexes. In Korea, students who had prior experience with environmental education, no experience using AR, and high awareness of the severity of fine dust showed moderate or low effect sizes and were statistically significant. However, for students in Australia, those who lacked the educational experience, those who had experience using AR, and those who had low awareness of the severity of fine dust were not statistically significant, so the effect size was not measured.

For "wearing masks" (Wear a mask when going to and from school during heavy sand or fine dust conditions), there was a significant increase in attitudes towards wearing masks after fine-dust environmental education among all respondents. The average attitude score increased from 3.07 before environmental education to 3.61 after environmental education. This increase was statistically significant, with a moderate effect size of 0.580, a positive effect. All groups showed a positive effect, regardless of sex, region of residence, experience with environmental education, experience using AR, or awareness of the severity of fine dust.

These results indicate that the environmental education program was effective in changing attitudes towards personal hygiene and wearing masks in response to fine dust, with varying degrees of effectiveness depending on the sampling characteristics.

For "environmental education" (Participate in environmental education such as fine dust when an opportunity arises), the change in attitude after fine-dust environmental education was also positively improved. The average score increased from 2.48 before environmental education to 3.18 after environmental education, representing a statistically significant difference ($p < 0.001$). The effect size was measured as 0.611, indicating a moderate positive change. Regardless of sex, region of residence, experience with environmental education, experience using AR, or awareness of the severity of fine dust, all groups showed moderate or higher positive effects.

For "waste separation and cleaning" (Separate and recycle waste properly, and thoroughly clean the surroundings), students' willingness to separate and clean waste increased slightly after fine-dust environmental education. The average increased from 2.94 to 3.34, representing a statistically significant difference ($p < 0.001$). The effect size was 0.399, indicating a small positive effect. Korean students had a moderate effect size, and all characteristic groups showed small sized effects. However, there was no statistical significance for the group in Australia for those without educational experience and those without experience using AR.

For "silence" (Do not run or engage in rough play in the classroom), students' willingness to be quiet in the classroom increased after fine-dust environmental education. The average score for this behavior increased from 2.70 to 3.28 among all respondents, which was statistically significant ($p < 0.001$) and had a moderate effect size of 0.525. The average difference was 0.5 or more for most groups, except for those who had low awareness of the severity of fine dust. This difference was statistically significant regardless of sex, region of residence, previous environmental education, or previous AR experience. The effect size was also mostly 0.5 or higher, indicating a moderate positive effect.

For "ventilation" (Ventilate indoor air of the classroom after a fine dust warning has ended), students' attitude toward ventilating the classroom improved after fine-dust environmental education. Among all respondents, the average increased from 2.73 to 3.40, representing a statistically significant difference ($p < 0.001$). The effect size was 0.649, a moderate overall effect. Classroom ventilation also showed a statistically significant difference of 0.5 or greater for all characteristic groups, regardless of sex, region of residence, experience with environmental education, experience using AR, or awareness of the severity of fine dust. The effect size was moderate, indicating a positive effect regardless of characteristics.

For "home cleaning" (Cleaning and organizing whenever you have a chance), the average score among all respondents increased from 2.71 before environmental education to 3.31 after environmental education, representing a statistically significant difference ($p < 0.001$). The effect size was 0.518, indicating a moderate positive effect. When analyzed by characteristics, all groups showed an increase in score regardless of sex, region of residence, experience with environmental education, experience using AR, or awareness of the severity of fine dust, with statistically significant results. The effect sizes were all moderate or greater than 0.4, suggesting that fine dust environmental education can induce positive change.

For "home ventilation" (Regularly ventilating indoor air every day when there is no fine-dust warning outdoors), the average score increased from 2.56 to 3.32 after environmental education, showing a statistically significant difference ($p < 0.001$) and a moderate effect size of 0.702. All groups, regardless of sex, region of residence, environmental education experience, AR usage experience, or fine-dust severity awareness, had a score increase between 0.39 and 0.75 with statistically significant results. The effect sizes were all equal to or greater than 0.4, indicating a low to moderate effect size.

4. Discussion

4.1. Changes in Awareness of the Severity of Fine Dust

Based on data analysis, we found that an educational program utilizing environmental education and augmented reality (AR) technology can be "effective" in increasing students' awareness of fine dust. "Effective" in this context refers to the ability to capture students' attention and deliver information in an engaging manner. This approach enhances students' motivation, participation, and understanding, leading to better comprehension of information and increased potential for behavioral development to protect their health. In this sense, the use of AR technology is considered to enhance active learning strategies. AR merges the real environment with virtual objects, providing learners with new experiences and problem-solving opportunities. These experiences improve students' academic achievement and increase their interest in learning [27,28]. The use of technology, such as educational games and simulations, can also enhance students' participation and learning outcomes [29,30]. Visual materials like multimedia can facilitate the understanding and retention of complex information [31]. Implementing these methodological effects in environmental education can improve students' environmental awareness, knowledge, and attitudes [32], significantly promoting their environmental and sustainability awareness [33].

Compared to other studies, our results demonstrated a similar positive impact of other environmental education on plastics for secondary school students [34]; environmental fact, concept, and generalization for secondary and junior college year-one students [35]; air, water, land and living organisms for students from the ninth through twelfth grade [36]; global and local environmental issues for secondary school students [37]; and materialism values and environmental knowledge for high school students [38]. Increase in awareness was consistent across all demographic groups. For instance, student participation in education significantly enhanced their understanding of air pollution and proved effective in promoting measures to reduce exposure [24]. It was also discovered that individuals with higher levels of education have lower mortality rates, even when exposed to air pollution [39]. This suggests that a high level of awareness about fine dust can improve the ability to manage its effects. Therefore, environmental education can offer information about the causes, impacts, and prevention methods of pollution. This leads to improvements in awareness and understanding, and further encourages participation for societal change and environmental protection [40].

From the changes in awareness of the severity of fine dust, we gained insights into what we can expect from the education. We confirmed the benefits of the program for both male and female students, especially for female students, who showed a larger effect size. This suggests that female students are more responsive to environmental education initiatives. In addition, the impact of educational interventions was consistent among students in both South Korea and Australia. This highlights the global relevance of educational programs that aim to raise awareness of fine dust levels, regardless of regional differences. Furthermore, the results indicate that environmental education and AR experiences have a lasting and cumulative effect, implying that ongoing and repeated environmental education can positively influence awareness enhancement. Notably, students with low initial awareness of fine dust improved more after the education, emphasizing the need for customized educational efforts for students with limited prior knowledge of fine particulate matter.

4.2. Attitude Changes in Response to Fine Dust

The fine dust environmental education had a positive impact on students' attitudes, as shown by the very low significance level (p-value) and the large t-test value (or effect size). The effect sizes for each attitude to fine dust varied, but they were all greater than 0.2, which is considered a small effect size. The largest effect size was observed in weather check, followed by medium effects in areas such as home cleaning, activity restraint, personal hygiene, wearing masks, environmental education, and ventilation. The rest of the areas had small effects. Therefore, it can be confirmed that students' attitudes have improved compared to pre-survey after fine-dust environmental education, indicating an increase in students' willingness to actively participate in efforts to protect themselves and preserve the environment.

This result is consistent with previous research. A study on the awareness, knowledge, and attitude towards biotechnology among Ethiopian high school students found a correlation between students' awareness and attitude [41]. Another study investigated the relationship between attitude towards science and academic achievement among elementary and middle school students, and meta-analysis results revealed an overall positive and moderate relationship between attitude towards science and learning achievement [42]. Research on whether public awareness, knowledge, and participation can improve climate change adaptation found a strong connection between active participation, awareness, and knowledge of climate risks. This can change participation attitudes and have a positive impact on behavior. Additionally, students who were highly aware of the severity of fine dust showed a greater change in attitude after receiving fine-dust environmental education [43].

Because both awareness and attitude improved after our environmental education in this study, it can be inferred that they are correlated. However, it is not always true, as described in [44]. Therefore, fine-dust environmental education should be interpreted as one way to increase the possibility of improving awareness and attitude, rather than establishing a cause-and-effect relationship. Most importantly, environmental education can play a role in making students aware of the severity of fine dust and interested in various information about it.

4.3. Environmental Education in Korea and Australia

Australia and Korea have significant differences in air pollution levels. Australia is known as a relatively clean air country with low levels of air pollution. In contrast, Korea tends to have higher air pollution. Nevertheless, there are valid reasons why both Australia and Korea should conduct environmental education on air pollution. First, environmental issues must be solved based on a sense of community worldwide. Although Australia currently has relatively low air pollution, it still needs to prevent and maintain it through continuous environmental education and interest. In addition, it is necessary to have common knowledge and awareness of air pollution with other countries with high air pollution such as Korea to respond to international issues. Second, air pollution is a global issue that transcends national boundaries. Air pollution can affect other regions and countries by moving pollutants in the atmosphere by wind. Even if only one country makes educational efforts for good quality air, the results of the effort are not guaranteed without participation from neighboring countries and the world. Therefore, all countries should conduct education on air pollution issues and share related knowledge and information to contribute to the protection of the regional and international atmospheric environment. Third, air pollution is a problem that directly affects human health, especially children in their growth period who can be relatively more affected. It is essential to recognize it as a core issue and educate them through the education system not only to convey the importance of environmental protection and correct knowledge but also to enable them to protect their health themselves. Both Australia and Korea are equipped with the appropriate education and environment for the next generation and should consider continuous interest and action.

4.4. Roles of AR in Environmental Education

Some studies have described that AR-based education often requires specialized equipment, giving rise to potential cost and accessibility issues in certain schools and regions, particularly in underdeveloped or developing countries [45,46]. Additionally, the use of AR can lead students to focus more on technology than on real environmental problems and emphasize technology over content [47,48]. Research results also indicate that AR-based environmental education programs may not be more effective than traditional methods in promoting specific skills, such as critical thinking and problem-solving [49]. However, the prevailing opinion is that AR generally has a positive impact on environmental education, and the implementation of AR served two specific roles in this study.

The first role was to address situations where real-life experiences are impossible within the realm of experience. Fine dust is harmful to the human body, yet it remains invisible, untouchable, and imperceptible. The only way to introduce experiential elements into classroom education in this context is to leverage digital technology, such as AR in this study. It is important to note that education on fine dust is a challenging subject that necessitates reliance on theoretical education.

The second role was to maximize the educational impact through experiential education. Text-based learning has limitations in effectively stimulating students' motivation and can result in boredom [50]. On the other hand, experience-based learning methods such as AR or VR have a more positive impact on education compared to text-based learning. The educational benefits of using AR or VR have already been demonstrated in numerous studies. The use of AR can serve as an effective tool for delivering information through more engaging learning, capturing students' interest and making the process enjoyable. It can establish a stronger connection between recognition and attitude by bridging the gap between reality and digital through an enhanced technique based on experience-based learning. Notably, it has been confirmed that AR can enhance the effectiveness of education by enabling students to actively participate in learning and comprehend the concept of fine dust more vividly [51–53]. Although this study did not incorporate tools to measure the effectiveness of AR in our education program, numerous studies consistently demonstrate that AR or VR technologies generally exert a positive influence. It is likely that the use of AR technology played a significant role in achieving the observed results in this study.

4.5. Limitations of the Study

This study, which had a small sample size of 90 participants, has some limitations. Small sample sizes can impair the accuracy of statistical inferences and affect the reliability and generalizability of the results. In particular, small effect sizes and insignificant results can be caused by small samples. However, there are some solutions to this problem. Firstly, even if it is difficult to obtain significant results due to a small sample size, it is possible to determine whether there is a significant difference by checking the effect size. If the effect size is large, statistically significant results can be obtained even in a small sample. Secondly, it is somewhat possible to check statistical significance using higher significance levels (e.g., $p < 0.01$) in small samples. This helps to exclude results that are not statistically significant and to evaluate the results with a more rigorous criterion. Thirdly, if attitude changes are consistently observed in a small sample, the reliability of the data can be ensured to some extent.

In this study, the level of p was established very low, which can be said to be reliable. In fact, the results of the impact of fine-dust environmental education on students' awareness and attitudes consistently showed positive improvements in most characteristic groups. Even though there are some limitations due to the small sample size, it is still considered to provide significant results. In other words, this study provides early evidence of how fine-dust environmental education can affect students' awareness and attitudes and provides suggestions for the direction of future research in the field by attempting research on the topic and showing the results.

5. Conclusions

Fine dust is a major environmental concern that seriously affects our health and the environment. In urban areas, the concentration of fine dust tends to increase due to industrialization and transportation, leading to an increase in health problems. This issue is important regardless of the country, making it crucial to improve students' awareness and attitude through fine dust environmental education.

We conducted an AR-based fine-dust environmental education program for elementary and middle school students and examined its impact on their awareness and attitude. Our findings confirmed that the program improved students' overall awareness of fine dust, with attitudes also changing positively after the education. These effects were statistically significant and common across most characteristic groups, with improvements observed in students' attitudes towards weather checks, activity restraint, personal hygiene, wearing masks, waste separation and cleaning, classroom silence, ventilation, home cleaning, and home ventilation. These results suggest that environmental education can help students develop a willingness to protect their own health through positive changes in their awareness and attitudes.

The results also have important implications for educational institutions and teachers. Continuous and systematic environmental education is necessary for all students to improve their awareness and attitudes towards environmental issues, as those who do not receive education may be more vulnerable to fine dust. While policy intervention is necessary for environmental problems such as fine dust, it is difficult to solve these issues through policy alone. If a policy is not based on changes in people's awareness and attitudes, its chances of success are low. Our study indirectly explains that policy effectiveness can be maximized through educational intervention alongside policies related to fine dust. By changing students' awareness and attitudes through education, we can help solve environmental problems. If policy changes are combined with this approach, environmental policies can be successfully implemented.

The use of AR in our fine-dust environmental education program was an indispensable choice. Fine dust is not suitable as an experiential learning subject for maximizing learning effects, so AR helps overcome situations where only theoretical learning methods can be used in the classroom. This advanced technology can be considered an effective educational tool for inducing students' interest and participation in the program.

Finally, fine-dust environmental education requires expertise and cooperation across various fields including technology, environment, and education. Our study found that it is difficult to maximize educational effects without introducing new technologies. Therefore, it is important to introduce new educational methods that allow students to experience and participate in their own learning. We suggest that educational institutions and teachers continuously develop educational programs using digital technology to raise awareness and form positive attitudes towards environmental issues that require international cooperation such as fine dust. This will help empower students for a healthier and more sustainable environment. Additionally, efforts should be made to explore ways to ensure the long-term retention of knowledge and behavior changes.

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