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The Role of integrating AI and VR in fostering environmental awareness and enhancing activism among college students

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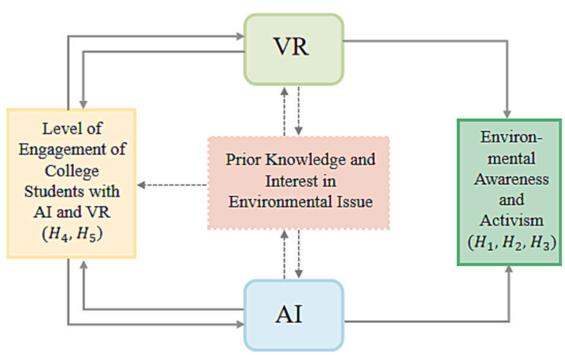
HIGHLIGHTS

- Involvement with AI and VR may refine exposure to environmental knowledge.
- More environmental knowledge and activism levels are influenced by AI and VR.
- Via AI and VR in the classroom benefit environmental education.
- Students with intense ecological issues may be more susceptible to the AI and VR.

GRAPHICAL ABSTRACT



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ABSTRACT

Given the increasing concern about the destructive impact of sympathetic activities on the Earth, involving the next generation in environmental conservation is crucial. Therefore, this study aims to explore how artificial intelligence (AI) and virtual reality (VR) can strengthen college students' environmental awareness and encourage them to make a move on environmental issues. Four hundred college students from diverse socio-economic backgrounds participated in a six-month study, and 375 valid questionnaires were successfully collected. By combining AI and VR, we provided interactive and engaging courses to deliver knowledge about environmental issues and inevitable disasters. The research demonstrates that using AI and VR technologies to teach environmental challenges can significantly improve college students' understanding of these topics, assist them in developing a conservationist value system, and provoke them to carry on environmental advocacy. This study adopted scale items to measure college students' environmental awareness and activities. More isolated structural equation modeling validated the value of AI and VR in environmental education. Additionally, mediation and moderation analyses indicated that the strength of college students' ecological susceptibility and motivation indirectly influenced their enthusiasm and environmental awareness through AI and VR. Through comparative analysis, we found that AI and VR exert differential effects on college students. Further correlational and regression analyses demonstrated that raising college students' environmental awareness can effectively promote their pro-environmental behavior, offering them more critical agency, possibly without the need for continued use of AI and VR. Therefore, employing AI and VR in environmental education may effectively help

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young people in ecological sustainability. Ultimately, we discussed the current AI and VR technologies adoption in Chinese universities and proposed relevant policy implications.

1. Introduction

Environmental degradation and climate change endure multifaceted challenges that can exclusively be addressed through systematic and interdisciplinary approaches. Education policy and technological solutions are crucial in shaping democratic attitudes, actions, and values toward the environment. However, traditional environmental education methods have been criticized for failing to change students' attitudes and behaviors toward sustainability (Chen et al., 2020). With the combination of AI, VR, big data, 5G, and other digital technologies, It is potential for significant improvement in the shortcomings of traditional education systems (Gowda and Suma, 2017), leading to a historic transformation. Many industries have begun utilizing these digital technologies to achieve a more sustainable future (Bradu et al., 2022; Nayal et al., 2022). AI and VR are initially applied in the military sector, manufacturing and healthcare (Ali et al., 2023; Fuller et al., 2020; Gluck et al., 2020; Verdejo et al., 2023).

Recently, AI and VR could help strengthen environmental education and public pursuit (Grasse et al., 2023; Zidaru et al., 2021). By combining AI and VR, we can develop realistic simulations of environmental settings for training and education purposes. By integrating these technologies into environmental education, we are likely to overcome the limitations of traditional pedagogical approaches and promote more effective and enduring ways of learning. Multiple studies have shown that AI and VR can effectively boost people's ecological awareness and motivate them to adopt more sustainable practices (Javaid et al., 2022; Richard and Rajakumari, 2023). For example, VR simulations of plastic pollution can improve participants' desire to reduce plastic waste (Lege and Bonner, 2020). AI-powered chatbots can upgrade people's awareness of environmental issues and motivate them to come into operation (Bagher, 2020). Similarly (Beck, 2019), it was discovered that students' innovative thinking, problem-solving abilities, and appreciation for the established world improved in a VR-augmented AI learning environment. Several studies have examined how AI and VR may be used in environmental education to convince more students interested in and involved with environmental issues on campus. AI-based chatbots in environmental education have sharply increased students' knowledge and awareness of environmental concerns by finding that VR simulations may foster pro-environmental attitudes and actions among students. (Zhang et al., 2023) conducted on 186 university students after an AI-based educational system found that environmental education, environmental knowledge, and environmental attitudes are interrelated and significantly correlated. Multiple studies have explored the potential of VR to aid students and involve them in campus environmental issues (Shen et al., 2020). For instance, VR simulations have been utilized to supervise students about the impact of climate change and provoke them to initiate environmentally responsible actions (Li et al., 2022a). Students can use VR to learn about and explore pristine ecosystems and environments, which may inspire them to be more committed to wildlife conservation and sustainable development. Additionally, AI and VR can design group and community-based enlightening experiences to reinforce environmental awareness and inspire action. For example, students can collaborate in digital spaces to identify solutions to environmental issues and disseminate their findings to a broader audience (Alam, 2022).

AI and VR may provide pupils with individualized and flexible educational opportunities. This demonstrates the potential to make environmental education more fruitful and exciting for today's students. The use of AI and VR to improve environmental education obtains enormous promise. Combining AI and VR can provide a more immersive and interactive learning experience. When applied to environmental education and activism, AI and VR can deepen students' grasp of environmental concerns and inspire them to work toward a more sustainable future. However, more extraordinary investigation into the strengths and weaknesses of these technologies in this setting is required. This study aims to provide a reasonable and reliable explanation through empirical research and previous relevant research findings. This study can promote more effective environmental education and contribute to a sustainable future by preventing more isolated degradation of the global environment. Initially, VR can provide a more immersive and realistic experience. By combining AI's intelligent algorithms with VR's interactivity, college students can undertake more natural and authentic interactions with virtual environments. Furthermore, AI can offer more intelligent functions and services to VR. By AI algorithms and technologies, VR can achieve savvy scene generation, object recognition, behavior simulation, and other functionalities (Huang, 2018). VR may maximize environmental awareness among college students and provide more personalized and customized environmental education measures and sustainable policies. AI and VR can also provide students with personalized and flexible educational opportunities (Abdullah and Najib, 2014). This can make environmental education more effective and exciting for today's students. To investigate the function of AI and VR, we establish a structural equation model and perform a multi-angle analysis. Despite recent progress, how applying AI and VR in overall environmental education and activism, to deepen students' intriguing ecological issues and trigger them to strive for a more sustainable future, remains to be elucidated.

In this work, we offer research that uses AI and VR to help undergraduates become more environmentally conscious and politically active. We developed an integrated approach combining VR simulations with AI-powered chatbots for a truly engaging and immersive instructive experience. Our research recruited 400 undergraduates from various majors exposed to AI and VR interventions on environmental issues, including climate change, biodiversity loss, and environmental justice. We adopted an AI-VR model to improve students' environmental literacy, attitudes, and actions. We observed that students who participated in the AI-VR treatments increased their knowledge of environmental concerns, their affinity for the commonplace world, and their propensity to capture positive environmental action. In addition, our research emphasizes the necessity for ethical and inclusive AI-VR interventions in environmental education and the need to tackle intersectional environmental and social justice concerns. Predominantly, our study adds to the substantial body of Literature on the use of AI and VR in environmental education and demonstrates how these tools provide the potential to improve the efficiency and longevity of more conventional instructional methods. We highlight the need for continued study and cooperation in this area and our results' implications for educational policy and practice.

2. Literature review

The impact of digital technologies on the environment is evident. Numerous studies have examined the relationship between digitization (i.e., information and communication technologies and digital technologies), energy consumption, and carbon emissions from a macro or *meso* level (Zhou et al., 2019). These studies suggest that in cities with high innovation investment, the impact of the digital economy on carbon emissions is more significant. They also recommend that governments accelerate the construction of current digital infrastructure to provide intensive support for emission reduction effects in the digital economy. (Zhou et al., 2022) the digital economy has embellished one of the most remarkable economic, social, and environmental phenomena. This study considers the comprehensive effects of digital demand and supply on China's carbon emissions. Another study (Zhou et al., 2018) evaluates the carbon emissions of contradictory information and communication technologies sectors, proposing strategies to address the climate change challenges of the digital era. Additionally, (Li et al., 2022b) analyze the increasing impact of the diffusion of information and communication technologies on energy use by establishing a three-level structural decomposition model (Feroz et al., 2021). At the meson level, research has found that the development of the digital economy can help businesses improve information acquisition efficiency, thereby promoting the enhancement of enterprise value (Xiao et al., 2023). Furthermore, network manufacturing based on industrial big data and intelligent analysis can transform raw data into valuable information, optimizing industrial structure and improving production efficiency (Cao, 2022). Moreover, from a macro perspective, it has been discovered that the development of the digital economy can stimulate an increase in entrepreneurial activities, enrich entrepreneurial resources, and promote high-quality economic growth (Zou and Chau, 2023).

AI and VR have received significant attention and discussion in the field of the digital economy. In recent years, many studies have explored the potential of AI and VR in intensifying ecological awareness and actions among university students. These studies have revealed the beneficial impact of AI and VR in improving environmental awareness and low-carbon lifestyles. Some studies emphasize the importance of AI in augmenting ecological awareness. Evidence provided by (Chiu, 2021) suggests that AI-driven chatbots may assist in environmental education for students. Similarly, (Mon et al., 2023) developed a smartphone application that utilizes AI and machine learning algorithms to provide personalized suggestions for reducing carbon emissions (Grasse et al., 2023). These tools maintain the potential to stimulate students' interest in environmental issues and inspire them to adopt more sustainable practices on campus. A grounded theory systematic review of environmental education for secondary students in the United States recognizes authenticity as the core of the environmental education process for American middle school students, thus exploring environmentally focused instruction based on theoretical VR models. Saikia et al. (2022) employs digital technologies such as video conferencing, mobile applications, and AI to provide new avenues for student cooperating in environmental conservation, aiming to cultivate environmental awareness and respect for nature among young people. (Bhatt et al., 2023) proposes that AI has both direct and indirect impacts on environmental pollution control by introducing innovative technologies, products, and models to reduce environmental pollution. (insert references), and (insert references) found that combining AI with extensive data can expand the scope of environmental monitoring and effectively reduce water pollution. These valuable studies provide abundant evidence for AI in environmental governance. This article aims to explore the impact mechanism of AI on environmental awareness among college students from an alternative perspective.

VR has additionally been used to teach kids about environmental issues. (Urueta and Ogi, 2020) found that VR-based educational programs can improve students' environmental knowledge and attitudes. A similar study indicated that college students showed significantly increased empathy and emotional responses toward environmental challenges after participating in VR simulations. The research suggests that VR simulations may inspire students to go into action on environmental issues. VR simulations of oil spills have increased participants' inclination to fascinate with gallant efforts in research conducted by (Marougkas et al., 2023). VR has also been proven effective in expanding students' ecological awareness. (Ruan, 2022) developed a VR course that demonstrated the impact of climate change on the Great Barrier Reef to college students. The results showed improved students' environmental awareness and attitudes due to their participation in the program. Plastic pollution's impact on marine life represents a theme in a VR game used for developing college students. Research findings indicate that playing the game stimulates students to learn more about plastic pollution and take measures to reduce it. College students are also utilizing VR to drive environmental conservation efforts. (Nelson et al., 2020) created a VR oil spill scenario to involve students in green issues. The results signaled an increased devotion to bring into action among students after experiencing the VR simulation. Similar efforts have been made by involving students in environmental awareness campaigns through VR simulations of forest fires. The research concludes that VR simulations significantly enrich college students' environmental awareness and actions. VR educates children about environmental issues (Hsu et al., 2018).

The employment of AI and virtual VR can potentially increase college students' environmental consciousness and guide. Chatbots, smartphone applications, and VR simulations driven by artificial intelligence are valuable tools for raising awareness among students about ecological concerns and hearten them to act. However, further study is required to ascertain the most effective methods to embrace such technologies to raise college students' environmental consciousness and involvement.

3. Preliminary

In this section, we provide specific definitions for five relevant hypotheses to analyze the impact of integrating AI and VR on promoting college students' environmental awareness and environmental activism.

H1: More elevated levels of environmental consciousness and activism among college students may associate with increased use of AI and VR. Involvement with AI and VR may refine exposure to environmental knowledge, raising environmental consciousness and activism and lending credence to the notion mentioned earlier (Zhou, 2022). Learning about environmental concerns via more conventional means may be less effective than immersive and interactive experiences (Chen, 2010). According to this theory, AI and VR may increase university students' environmental consciousness and activism.

H2: More extraordinary environmental knowledge and activism levels among college students are more likely to be influenced by AI and VR. Recent studies have demonstrated that pro-environmental activities and attitudes can be predicted by individuals' familiarity and interest in environmental issues (Bhatt et al., 2023). AI and VR are significant in cheering students to perform an action on environmental issues. AI and VR provide the potential to ameliorate awareness of environmental protection through immersive and interactive experiences, as previous research has shown that partaking is a crucial predictor of environmental attitudes and behaviors (Yu and Lin, 2019). Therefore, it is plausible to accept such hypotheses.

H3: Using AI and VR in the classroom is more likely to benefit students who are more familiar with and passionate about environmental issues. Interventions aims at heightening pro-environmental actions and attitudes have manifested varying degrees of success, depending on factors such as the target audience's environmental literacy level and occasion (Xu, 2022). The indirect impact of AI/VR applications on the environment strengthens the awareness and activism of these students, as they are more likely to share in and better grasp the environmental concepts presented by such technologies.

H4: The desire of students to ameliorate environmental awareness and enthusiastically participate in environmental actions, which is expected to mediate the relationship between AI/VR exposure, environmental education, and their atmospheric sense, understanding, and behaviors. This hypothesis suggests that college students' context awareness level may moderate their enthusiasm to be responsible for environmental actions, as individuals with intender levels of ecological challenges may benefit more from AI and VR applications in environmental education. Research has shown that aware individuals of their impact on the Earth are more likely to take measures to conserve it (Hoti et al., 2023). Therefore, college students with intense levels of ecological issues may be more susceptible to the influence of AI and VR in environmental education than those with lower environmental awareness levels.

H5: The motivation of students to use AI and VR for understanding environmental issues, which is expected to moderate the relationship between AI/VR exposure and environmental concerns, competing, and understanding. This hypothesis suggests that the connection between students' exposure to AI and VR-based environmental education and their appreciation of environment, activism, and understanding may be mediated by their inspiration to learn about environmental issues with AI and VR. Students' environmental consciousness, activism, and knowledge are anticipated to be positively associated with their commitment in AI and VR-based environmental education.

Overall, the assumptions show that AI and VR provide the potential to increase environmental perception and activism among college students; however, the usefulness of these technologies may depend on the level of familiarity, interest, and participation each student has with the medium (Chen et al., 2020). These theories provide the groundwork for future studies into AI and VR's role in mobilizing college students on environmental issues. As shown in Fig. 1, it is expected that college students' environmentally aware and activism will directly increase due to the use of AI and VR. Additionally, it is anticipated that students' eagerness to get busy with environmental conservancy will influence their participation in AI and VR, indirectly affecting their green issues and activism (Zhai et al., 2021). Lastly, students with deeper inducement toward environmental issues are expected to be more likely to moderate the relationship between AI and VR and their earth-friendly perception and activism levels (Figs. 2 and 3).

4. Methodology

This study employed structural equation modeling (SEM) to base the complex relationships among multiple variables (Fan et al., 2016). Confirmatory factor analysis and regression analysis were used to represent the paths of correlation between certain variables in the model. Mediation analysis was conducted to examine the role of mediator variables. Moderation analysis was employed to explore the extent and direction of the influence of moderator variables.

4.1. Selection of quantitative indicators

The New Ecological Paradigm (NEP) Scale items (Pienaar et al., 2013) would be modified to assess environmental attitudes. Attitudes toward environmental preservation, resource usage, sustainable development, and other ideas regarding the human-nature dynamic are estimated with the help of the NEP. To evaluate environmental behaviors, we propose utilizing modified items from the Environmental Behavior Inventory (Chawla and Cushing, 2007). The EBI assesses how often people participate in eco-friendly actions, including recycling, energy efficiency, and alternative modes of transportation. To quantify this concept, we develop research-specific items that evaluate how often and in what ways participants have used AI and VR for environmental education, involvement, and advocacy. The poll also contains primary demographic questions about respondents' ages, sexes, ethnicities, fields of study, and education levels. The instrument's validity and Reliability would be ensured by pilot testing with a subset of college students. The response options for the scale were designed in a Likert format, ranging from "completely agree," "somewhat agree," "neutral," "somewhat disagree," and "completely disagree" with a scoring system of 5 to 1 for positively worded items and 1 to 5 for negatively worded items.

4.2. Structural equation modeling

Structural Equation Modeling (SEM) is a statistical analysis method used to explore the relationships between variables and the fit of a model (Fan et al., 2016). It can simultaneously consider the relationships between observed and latent variables and evaluate the fit of a theoretical model through measurement and structural models. In SEM, the relationships between observed variables and latent variables can be represented by path coefficients. Path coefficients indicate the direct or indirect effects of one variable on another. Observed variables are directly observable, while latent variables are not directly observable but can be indirectly estimated by measuring observed variables. SEM can be used to validate the fit of a theoretical model, evaluate causal relationships between variables, generate predictions, and compare models. It is widely concerned in social sciences, educational research, psychology, and other fields.

4.3. Regression analysis

Regression analysis is an essential statistical method to examine the

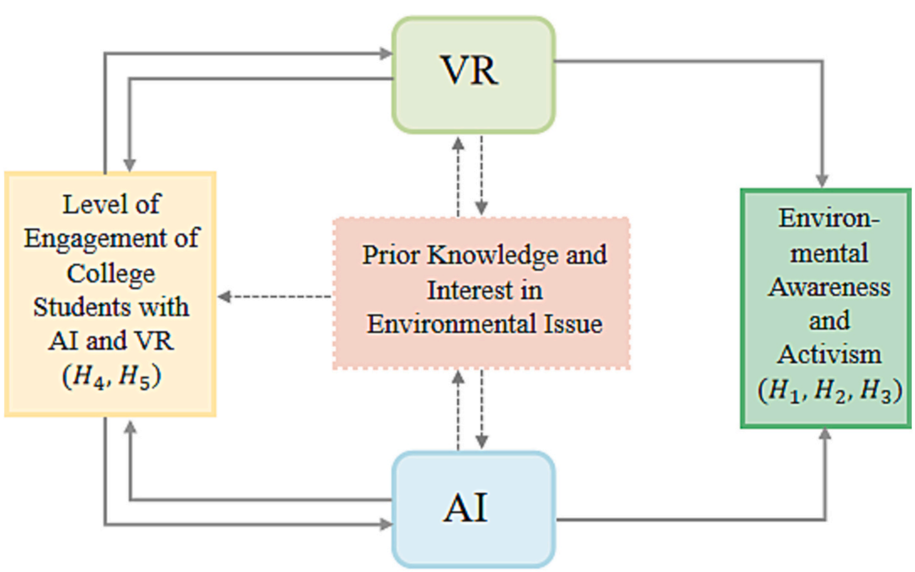

Fig. 1. The Correspondence Between Assumptions. Hypothetical associations between variables are shown as arrows in the model. The Arrows presented and show direct effects from the use of AI and VR technologies to environmental awareness and action is denoted as the arrow connecting the use of AI and VR with engagement, and the predicted mediating effect is denoted by the arrow from engagement to environmental awareness and action. assumes that there are moderating effects between environmental awareness, activism and participation, as shown by the arrows from prior knowledge and interest to the link between participation and environmental awareness and activism.

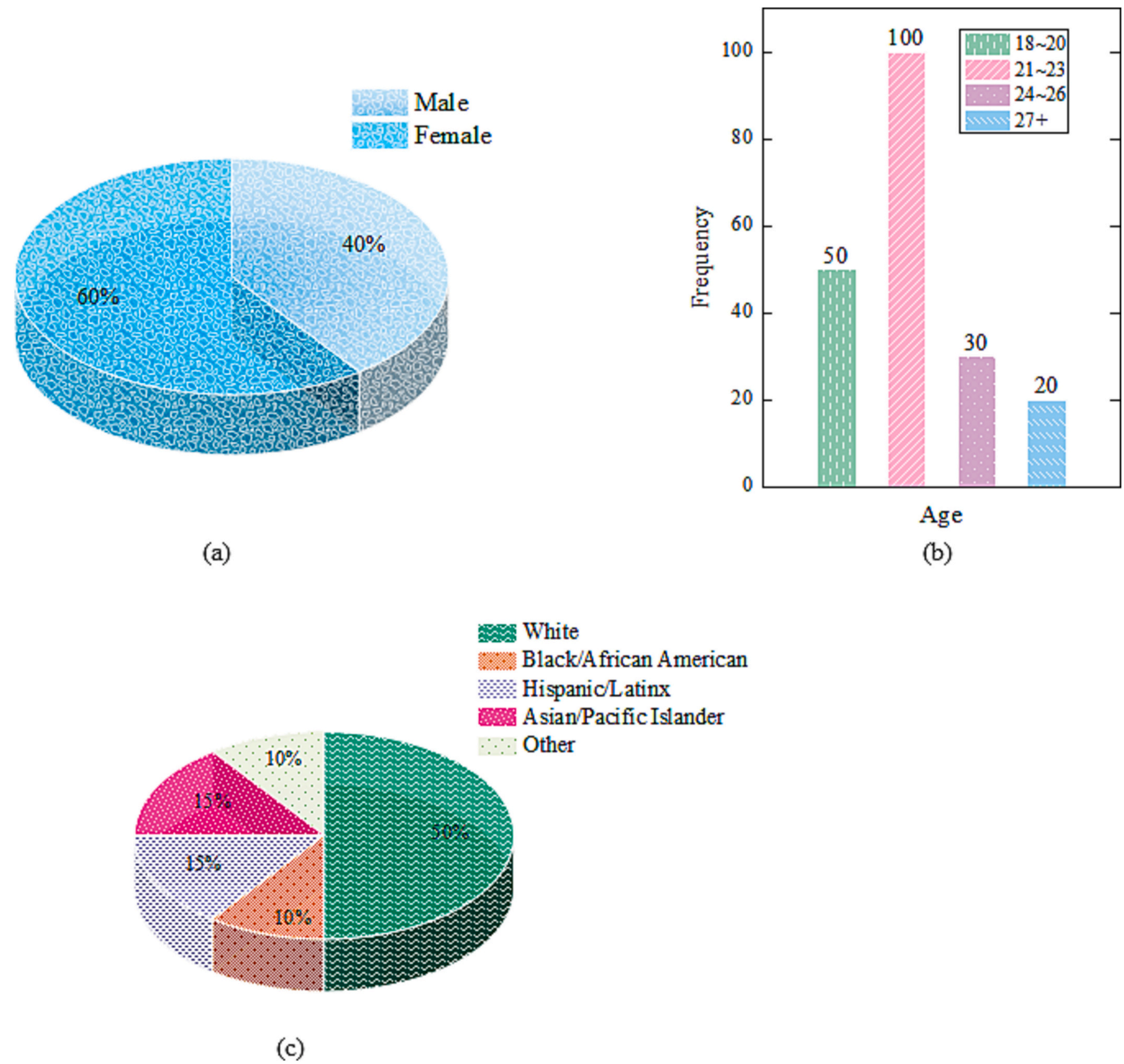

Fig. 2. The Distribution Characteristic of Respondents. **(a)** denotes the Sex; **(b)** denotes the Age; **(c)** denotes the Ethnicity.

relationship between independent and dependent variables (Freund et al., 2006). It involves establishing a mathematical model to describe the impact of independent variables on the dependent variable and making inferences and predictions by estimating the model's parameters. In regression analysis, independent variables explain the variation in the dependent variable, while the dependent variable represents the variable being defined or predicted. Regression analysis aims to identify the relationship between independent variables and the dependent variable and determine the strength and direction of this relationship.

4.4. Mediation analysis

Mediation analysis remains a frequently used statistical method to explore relationships and mechanisms between variables (Iacobucci, 2008). It is a method used to explain how an independent variable influences a dependent variable. Mediation analysis reveals the relationship between variables by examining the mediating role of a mediator variable between the independent and dependent variables. Mediation analysis aids us in grasping why an independent variable impacts a dependent variable and through which mediator variables this impact is transmitted. Mediation analysis aids us in capturing why an independent variable affects a dependent variable and through which mediator variables this impact is transmitted.

4.5. Moderation analysis

Moderation analysis is a method used to examine whether a variable moderates the relationship between an independent variable and a dependent variable (Memon et al., 2019). It explores the extent and direction of the influence of a moderator variable on the relationship between the independent and dependent variables. The moderator variable represents a variable that affects the relationship between the

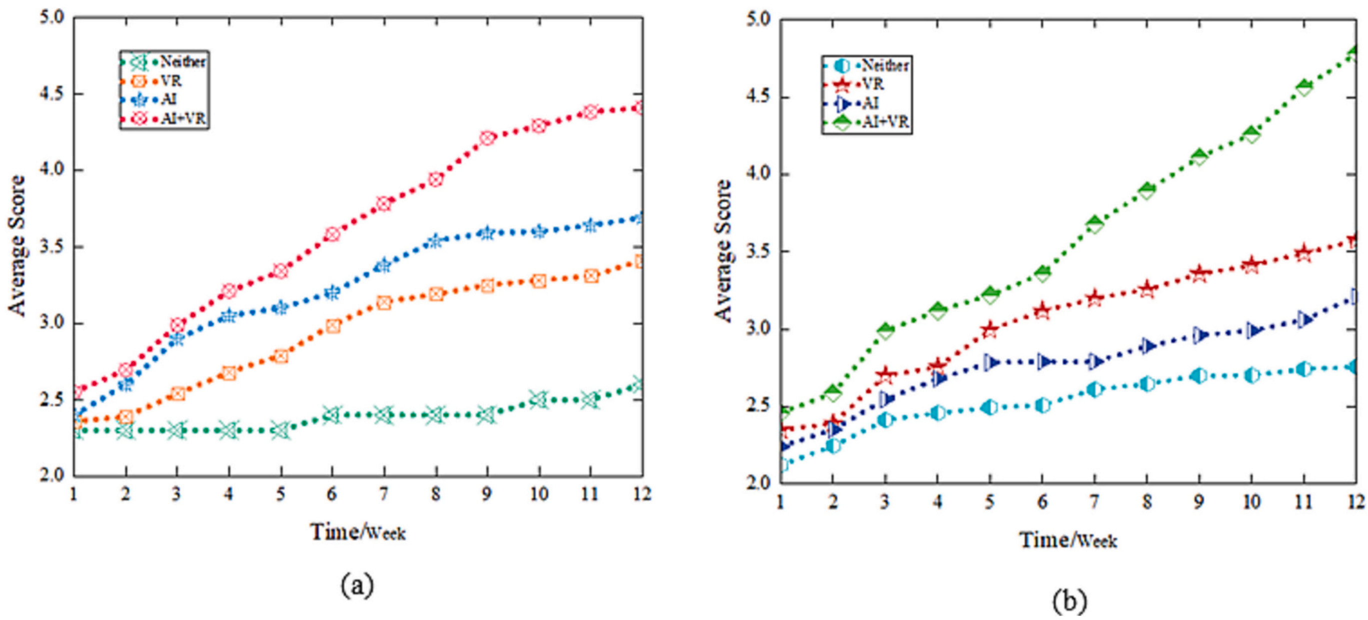

Fig. 3. The Comparison Analysis. **(a)** denotes the Environmental Awareness; **(b)** denotes the Environmental Activism.

independent and dependent variables, and it can either elevate or diminish the impact of the independent variable on the dependent variable. Moderation analysis assists us in understanding whether the effects of an independent variable on a dependent variable differ under different conditions.

5. Empirical analysis

5.1. Data acquisitions

We surveyed multiple universities in China, collecting 400 responses to gain a more genuine understanding of how AI and VR can help improve green consciousness and action among college students. To ensure our sample accurately represented the entire student population in China, we distributed the survey to institutions with diverse student backgrounds. We invited participants to wear Adventure VR glasses and experience various environmental scenarios, like rainforests, oceans, and polar regions, to stimulate their interest and awareness of natural conservation. (Zhou, 2022) Through virtual field trips to nature reserves and polluted areas, we aimed to improve their understanding of environmental issues' current state and impact, thereby promoting environmental consciousness. Additionally, we simulated scenarios of environmental conservation actions through VR, allowing students to directly experience the importance and challenges of wildlife conservancy and pushing them to give a view. Each VR glass had a corresponding student account connected to the participants' smartphones via the Adventure app and generated relevant log data.

we required participants to install an AI chatbot application that provided personalized nature-mindedness recommendations based on college students' interests and behavioral data. By analyzing their browsing history and preferences, we recommended appropriate knowledge, news, articles, videos, and activities related to conservation area. Participants were invited to talk about their environmental literacy, their views on AI and VR to promote environmental activism, and their openness to undertaking direct action. To increase response rates and ensure broader participation, we distributed the survey in digital and physical formats and conducted a six-month follow-up survey. The participants were randomly assigned to three groups: AI only (125 participants), VR only (125 participants), and both AI and VR (125 participants). To present comprehensive experimental results, we initially surveyed and recorded the participants' sustainability mindset and activism, which were later compared. Throughout the experiment, we updated the data every two weeks. At long last, we collected 375 valid questionnaires. We conducted a multidimensional analysis of these 375 questionnaires to validate the hypotheses proposed. Our research results were presented by the R programming language.

5.2. Data preprocessing

To further the Reliability and accuracy of the research findings, we performed data cleaning and preprocessing after consolidating and organizing the two questionnaire formats.

(1) Missing value handling

For variables with a steep missing rate (80 %), low coverage, and low importance, they were directly obliterated. If the variable follows a uniform distribution, it is swelled with the mean value. If the variable exhibits significant skewness, it was supplied with the median value.

(2) Outlier handling

Outliers in variables were identified through box plots and statistical methods based on the Median Absolute Deviation (Mon et al., 2023). The outliers were replaced with either the mean or median value, ensuring a coherent and efficient approach with minimal information loss. This preprocessing step is crucial for subsequent structural equation modeling.

(3) Univariate importance

Since nature-consciousness and activism cannot be directly measured, we established multiple equivalent indicators to represent them. For example, the strength of planet-friendly perception can be reflected by indicators such as the channels for obtaining ecological information and whether the concept of 'lowing carbon' should be integrated into college students' consciousness. Variables like the frequency of disposable chopsticks and plastic bags per week can represent the strength of environmental activism. We analyzed the correlation between the target and independent variables with Pearson correlation coefficients and chi-square tests, selecting important and highly correlated indicators.

(4) Normalization

There can be significant differences in their numerical values due to the inconsistent scales of other observed variables. Therefore, the data are scaled by a certain proportion to fall within a specific range, facilitating comprehensive analysis. We used Z-Score normalization for this purpose.

(5) Sparsity handling

For variables like gender, sparsity handling is performed by considering them as sparse dummy variables with values of 0 and 1. If a variable provides many conflicting values, the deals with fewer occurrences are grouped as 'Rare' based on frequency. Sparsity handling is beneficial for constructing subsequent structural equation models.

5.3. Descriptive statistics

The primary information obtained from the 375 survey questionnaires is presented in Fig. 2. Fig. 2 (a) shows the gender distribution of college students, with males accounting for 40 % and females accounting for 60 %. Although research suggests that the impact of AI and VR on ecologically aware and activism among college students may be uninfluenced by gender (insert reference), we ensured a reasonable gender proportion. Fig. 2 (b) displays the age distribution of college students, with the majority falling within the 21–23 age range, mostly in their sophomore and junior years. Fig. 2 (c) presents the ethnic distribution, which greatly ensures the generalizability of our study.

5.4. Mechanism analyses

5.4.1. Reliability and validity analysis

The NEP scale consists of 10 items, while the EBI scale consists of 7 items. After conducting a reliability analysis, the Cronbach's Alpha coefficient for the NEP scale was found to be 0.81, and for the EBI scale, it was 0.88, indicating our questionnaire design is reasonable (Roberts and Priest, 2006). We employed principal component analysis to extract factors from these items. Three elements with eigenvalues greater than one for the NEP scale were extracted, accounting for a cumulative variance contribution of 75.053 %. The KMO value was 0.817. These three factors were identified 'Environmental Knowledge (EA1)', 'Environmental Values (EA2)', and 'Environmental Attitudes (EA3)'. Two elements with eigenvalues greater than one for the EBI scale were extracted, accounting for a cumulative variance contribution of 82.937 %. The KMO value was 0.771. These two factors were mentioned, 'Public Domain Environmental Behavior (EC1)' and 'Private Domain Environmental Behavior (EC2)'. The factor structures of both scales are presented in Tables 1 and 2. The KMO values and factor loadings indicate that these items effectively represent their corresponding constructs, and each item is strongly associated with its respective construct (Ang and Huan, 2006).

Table 1
Extract common factors (CNEP). * indicate $p < 0.05$; ** indicate $p < 0.01$; *** indicate $p < 0.001$.

Item	Factor1	Factor2	Factor3
1	0.792		
4	0.844		
6	0.825		
2		0.755	
3		0.841	
8		0.743	
9		0.812	
5			0.854
7			0.721
10			0.738

Table 2
Extract common factors (EBI). * indicate $p < 0.05$; ** indicate $p < 0.01$; *** indicate $p < 0.001$.

Item	Factor1	Factor2
1	0.788	
3	0.914	
6	0.726	
7		0.877
2		0.729
4		0.818
5		0.745

5.4.2. Structural equation modeling

Based on the current research on AI and VR in environmental education, this study established a structural equation model and conducted a confirmatory factor analysis to examine two possible models: a single-factor model and a dual-factor model. The single-factor model involved either AI (Model 1) or VR (Model 2) for environmental education, which is the approach adopted in most existing studies. The dual-factor model combined AI and VR (Model 3) for environmental education. The model fit results are presented in Table 3, and considering various appropriate indices, Model 3 outperformed Models 1 and 2. All fit indices of Model 3 reached desirable standards, indicating an excellent fit of the model to the data.

For Model 3, we conducted confirmatory factor analysis, and the results are shown in Table 4. The Cronbach's Alpha coefficients for each construct were above the acceptable threshold of 0.70, indicating good internal consistency for each indicator (Diedenhofen and Musch, 2016; Harrington, 2009). These findings are consistent with previous research, which established a direct correlation between environmental awareness, activism, AI exposure, and VR exposure). Another study by (Pham and Sampson, 2022) found that eco-awareness significantly influences environmental activism and shows a direct correlation, and exposure to AI and VR decorate college students' environmental understanding and activism. Another study by (Nelson et al., 2020) found that exposure to AI and VR increases adult environmental behaviors. Predominantly, the confirmatory factor analysis results support the validity and Reliability of the measurement model for assessing college students' environmental awareness, activism, AI exposure, and VR exposure while validating hypotheses 1.2 and 3.

5.4.3. Mediation analysis

We use mediation analysis to validate hypothesis 4, and the results obtained by the four-step regression method (McNally, 2007) are shown in Table 5. In the first stage, with AI and VR as the independent variable (X), environmental awareness and environmental activism as the dependent variables (Y). The results showed significant effects on sustainable mindset and activism, aligning with previous research findings (Grasse et al., 2023; Lege and Bonner, 2020). In the second stage, with the use of AI and VR as the independent variable and students' goodwill to extend environmental awareness and actively captivate with environmental actions as the mediating variable (denoted as Me), statistically significant support was found, indicating that AI and VR exposure leads to a greater ardor among college students to learn about greener lifestyles, sustainable development and actively participate in linked environmental activities. In the third stage, we found that when environmental zeal is built. It significantly influences college students' earth-

Table 3
Results of structural equation model fitting. * indicate $p < 0.05$; ** indicate $p < 0.01$; *** indicate $p < 0.001$.

Model	χ^2	df	χ^2/df	RMSEA	NNFI	CFI
Model1	210.45	54	3.90	0.16	0.84	0.87
Model2	176.60	53	3.33	0.09	0.91	0.90
Model3	124.76	51	2.51	0.69	0.94	0.93

Table 4
Confirmatory factor analysis. * indicate $p < 0.05$; ** indicate $p < 0.01$; *** indicate $p < 0.001$.

Construct	Item	Standard error	Cronbach's Alpha
Environmental awareness	EA1	0.03	0.81
	EA1	0.04	
	EA1	0.05	
Environmental activism	EC1	0.02	0.88
	EC1	0.03	
AI & VR exposure	[AI & VR]1	0.02	0.84
	[AI & VR]2	0.03	
	[AI & VR]3	0.04	

Table 5
Mediation analysis results. * indicate $p < 0.05$; ** indicate $p < 0.01$; *** indicate $p < 0.001$.

	Dependent variable			
	Y (1)	Me (2)	Y (3)	X (4)
Y				0.155 (0.203)
Me			0.148** (0.094)	0.579*** (0.007)
X	0.217** (0.182)	0.463*** (0.182)	0.252 (0.992)	
Constant	18.*552* *(12.264)*	4.605 (17.412)	13.722 (16.131)	26.119*** (10.077)
Observations	125	125	125	125
R^2	0.442	0.544	0.508	0.518
Adjusted R^2	0.403	0.529	0.495	0.501
Residual Std. Error	6.150 (df = 123)	4.8240 (df = 123)	5.1560 (df = 122)	6.823 (df = 122)
F Statistic	5.326** (df = 1;123)	35.117*** (df = 1;123)	15.111*** (df = 2;122)	22.389*** (df = 2;122)

consciousness and activism positively and proactively. These three stages support the validity of hypothesis 4. In the fourth stage, we discussed whether the lifting of ecologically aware and environmental activism would lead to a dependence on AI and VR among college students, and the regression results were not significant. This is reassuring, as it suggests that as college students deepen their understanding and acceptance of the natural environment, they are more inclined to cause progressive and proactive changes without external driving forces or assistance, demonstrating their subjective agency. Furthermore, we conducted bootstrapping tests (Hongyi and Maddala, 1996). Table 6 shows that even after 1000 bootstrap samples, the indirect effect (ACME) remains significant, while the direct impact (Bhatt et al.) is insignificant, indicating a complete mediation. Put differently, when we control for Me when college students have zero environmental propensity, these technologies become ineffective.

5.4.4. *Moderation analysis*

We set college students' grounds for nature conservation and pursuit of sustainable development as the moderating variable (denoted as Mo), and we conducted an interaction analysis to examine the role of the moderating variable. To avoid multicollinearity (Alin, 2010), we centered the two variables involved in the interaction. Based on the interaction between college students' use of AI and VR and Mo, we validated hypothesis 5. After centering the variables, the regression results are shown in Table 7. Xc represents the centered independent variable, Moc represents the centered moderating variable, and Xc: Moc describes the interaction term after centering. We found that all coefficients are significant, indicating that when college students maintain an apparent and robust prompting for environmental safeguarding (Bhatt et al., 2023), they are more willing to launch into AI and VR classroom activities and show a strong interest in AI and VR. This advances their environmental awareness and demonstrates pro-environmental behavior.

Table 6
Bootstrapping test results. * indicate $p < 0.05$; ** indicate $p < 0.01$; *** indicate $p < 0.001$.

	Estimate	95 % CI lower	95 % CI upper	*P*-value
ACME	0.8081	0.1754	0.594	$< 1.5e-10$***
ADE	0.3131	−0.1160	0.128	0.249
Total effect	0.4162	0.0145	0.281	0.038*
Prop. mediated	2.3876	0.9987	8.343	0.038*

5.5. *Heterogeneity analysis*

5.5.1. *Comparative analysis*

The *t*-test revealed significant differences in environmental behavior and activism among college students in three conditions: AI only, VR only, and both AI and VR ($p < 0.001$) (Kim, 2015). Table 8 presents the average scores for each indicator, where sub-tables a, b, c, and d correspond to indicators EA1 (Min = 1, Max = 5), EA2 (Min = 1, Max = 5), EA3 (Min = 1, Max = 5), EC1 (Min = 2, Max = 5), and EC2 (Min = 2, Max = 5). A value of 0 indicates non-usage of the technologies, while a value of 1 indicates usage of the technologies. The results in Table 8 demonstrate significant differences in environmental behavior and activism among college students with AI only, VR, and AI and VR ($p < 0.001$). The combined use of AI and VR resulted in more significant average scores for all indicators, with increases of 1.15, 0.4, 0.55, 1, and 1.25 for EA1, EA2, EA3, EC1, and EC2, respectively, compared to participants by a single technology.

We are pleasantly surprised to find that the mechanisms of action for the two technologies exhibited differences. For NEP, the influence of AI was more significant. The AI-driven chatbot strengthens college students to seek answers to ecological advocacy and sustainable development-related questions. Before this, students possessed a vague understanding of the relationship between sympathetic actions and environmental outcomes. Even applying VR to simulate specific natural disaster scenarios, they wondered which behaviors could lead to those outcomes. However, through AI-based Q&A and intelligent recommendations, students were able to clarify the cause-and-effect relationship of their actions (Yu et al., 2023). The addition of VR promoted students' reality of the immense environmental damage caused by their actions through visual impact and a closer-to-reality experience (Ruan, 2022). These combined effects significantly improved NEP scores. Even without AI and VR-based environmental education, college students have already demonstrated an enlightened attitude toward environmental sustainability, resource utilization, and sustainable development (EA2 = 3.2). However, AI and VR environmental education still yielded the most splendid results. The improvement in EA3 showed almost consistent effects from both AI and VR, with a combined average score of 3.8. VR produced a broader impact on EBI. This may be related to the rapid urbanization in China (Tagulao et al., 2022; Yang, 2013). Although we tried to ensure the randomness and diversity of the sample, college students living in China have relatively limited knowledge about pristine forests, glaciers, and rivers. The realistic nature scene simulations provided by VR effectively compensated for this deficiency, resulting in higher scores.

Table 7
Moderation analysis results. * indicate $p < 0.05$; ** indicate $p < 0.01$; *** indicate $p < 0.001$.

	Estimate	Std. error	t value	P-value
Constant	41.81748	2.16832	59.223	$< 1.38e-10$***
Xc	4.17115	0.81344	15.479	$< 1.38e-10$***
Moc	0.64648	1.55518	6.589	$< 1.29e-7$***
Xc:Moc	0.27929	0.05637	2.155	$< 1.54e-8$***

Table 8
The average score of each factor. * indicate $p < 0.05$; ** indicate $p < 0.01$; *** indicate $p < 0.001$.

AI \ VR	0	1
0	2.31	2.83
1	3.14	4.56

(1) **EA1**

AI \ VR	0	1
0	3.20	3.43
1	4.05	4.25

(2) EA2

AI \ VR	0	1
0	2.43	3.19
1	3.41	3.87

(3) EA3

AI \ VR	0	1
0	2.64	3.52
1	2.90	4.28

(4) EC1

AI \ VR	0	1
0	**2.24**	**3.29**
1	**2.76**	**4.23**

(5) EC2

5.5.2. *Correlation analysis*

After factor extraction, we conducted a correlation analysis to examine the relationships between the dimensions. The results are presented in Table 9. We noted weak correlations between environmental knowledge, values, and eco-friendly technologies. This may be because multiple factors influence environmental knowledge, deals, and attitudes. However, we observed a strong positive correlation between environmental activism and environmental and consistent awareness with previous research (Karahan, 2012).

Table 9
The correlation of each factor. * indicate $p < 0.05$; ** indicate $p < 0.01$; *** indicate $p < 0.001$.

	EA1	EA2	EA3	EC1	EC1
EA1	1				
EA2	0.421***	1			
EA3	0.506***	0.421***	1		
EC1	0.621***	0.644***	0.727***	1	
EC2	0.788***	0.830***	0.860***	0.573***	1

EA1, EA2, and EA3 were used to measure college students' environmental awareness, while EC1 and EC2 were used to measure their environmental activism. For hypotheses 1, 2, and 3, based on bi-weekly score records, we obtained a frequency count of 12 for each factor after six months. We calculated the average of all frequencies for these three factors and examined the changes in their average scores over this period to validate the rationality of hypotheses 1, 2, and 3. Identically, we sought a similar approach to analyze the changes in environmental activism. Figs. 3 (a) and (b) represent the score variations of college students' environmental awareness and environmental activism, respectively, as the frequency of AI and VR usage increases. In Fig. 3 (a), we observed a significant advance in students' conservationist mindset with the increasing use of AI and VR in classroom teaching, reporting a direct correlation. However, the average scores reached a plateau starting from the 10th week, suggesting that the continuous use of this educational approach might make students feel less novelty and challenged, as they believe they have acquired sufficient environmental knowledge. Additionally, college students limited to campus environments may encounter homogeneous environmental issues with limited room for development. Fig. 3 (b) demonstrates a similar trend in environmental activism as Fig. 3 (a) but with a sustained and noticeable improvement. We are charmed to inspect these results, as AI and VR urge college students to absorb in adopting greener lifestyles and sustainable development, demonstrating tangible environmental behaviors. We, on top, found that AI sustains a more pronounced impact on broadening environmental awareness, while VR exerts a more persuasive influence on promoting activism. These findings are consistent with our previous experimental results and further validate the rationality of hypotheses 1, 2, and 3.

5.5.3. *Regression analysis*

We aim to explain regression analysis as to whether aggravating environmentally sensitive leads to increased pro-environmental behavior rather than solely being attributed to technologies use. The direct benefit of this analysis is that, after elevating college students' environmental awareness and their concern for environmental sustainability through AI and VR, they can implement concrete actions to foster the environment based on their own subconscious and psychological effects without the need for continuous use of AI and VR for environmental education. It scarcely requires updating on new environmental issues, which aligns with the principles of sustainable development. The regression model and results are presented in Table 10. We found that all

Table 10
Regression analysis results. * indicate $p < 0.05$; ** indicate $p < 0.01$; *** indicate $p < 0.001$.

Set	Coefficients	*P* value	Results
Constant	0.299***	<0.001	Reject
EA1 → EC1	0.323***	<0.002	Reject
EA2 → EC1	0.257***	<0.001	Reject
EA3 → EC1	0.598***	<0.001	Reject
EA1 → EC2	0.226***	<0.003	Reject
EA2 → EC2	0.178***	<0.0035	Reject
EA3 → EC2	0.645***	<0.001	Reject

variables passed the significance test, and the regression coefficients indicate a tangible and significant impact of respecting for nature on environmental activism (Piyapong, 2020). After positively influencing college students' ecological understanding through AI and VR, they knuckle down to against climate change based on the acquired environmental skills without developing a significant technological dependency.

5.6. Discussion

This study aimed to investigate the role of AI and VR in cultivating environmental literacy and activism among college students. The results demonstrate that the use of AI and VR can step up environmental awareness and promote actions toward sustainability. Previous research (Riza et al., 2023; Zhou, 2022) has hitherto indicated the potential of technologies-based interventions in improving pro-environmental attitudes and behaviors, and our findings are consistent with this. Furthermore, we conducted multidimensional and multi-angle experiments to ensure the Reliability and objectivity of the results. Explicitly, reliability and validity analyses indicated that our adapted scale items comprehensively and adequately captured college students' environmental awareness and activism, dignifying the credibility of the experimental results. The structural equation model effectively described the impact of AI and VR on improving college students' ecological consciousness and provoking their gallant actions. Mediation analysis provided robust evidence for hypothesis 4, as we employed a 4-step regression method (insert reference) to verify that the use of AI and VR inflates college students' environmental intentions, instigating them to care for the environment actively. Notably, this increase in environmental preferences does not require continuous use of AI and VR. Instead, through this classroom environmental education, college students become aware of the severity and urgency of environmental issues and develop intrinsic motivation. Moderation analysis leads us to believe that college students with more vital environmental bases exhibit more optimistic attitudes toward AI and VR to build up environmental awareness and activism. To ensure the stability of the results, we conducted a heterogeneity analysis. Comparative analysis suggests a direct correlation between AI and environmental awareness, while AI and VR may provide a more significant correlation with environmental activism. AI can provide precise recommendations and answers, helping college students understand environmental issues and develop a more profound respect for the organic world. On the other hand, AI and VR simulations provide college students with a sense of realism and immersion in natural disaster scenarios, stimulating them to accomplish proactive actions to improve the natural world. Additionally, correlation and regression analyses demonstrate that an increase in naturalistic intelligence directly leads to a significant meliorate of college students' environmental consciousness. This finding may inspire us to expedite sustainable environmental education for college students in the future.

Despite our constant emphasis on the importance of AR and VR in educating college students about maintaining a sustainable attitude toward environmental issues, these two technologies have yet to be universally adopted on Chinese university campuses (Qin and Gan, 2022), especially VR (Qin and Gan, 2022). China has consistently supported the development of high-tech enterprises with low financing thresholds and significant policy support (Zhou, 2008). However, AI and VR technologies in university education for sustainability present a bleak picture. Our interviews revealed that college students desire to contribute to China's sustainable development. However, their understanding of catastrophic, inevitable disasters is limited—for example, flooding, frequent fires, polar ice melting, and oil spills. College students mentioned that although they are aware of these events, most of their knowledge comes from the internet and news media, making them feel distant from their own lives. Additionally, college students feel uncertain about how to respond to grave natural disasters and ordinarily do not know where to start. While they operate AI software like ChatGPT, their search volume on environmental issues is relatively low, indicating a selective approach to organic minds and activism. Integrating AI and VR into university classroom teaching becomes essential. Although it may require some economic investment in the abbreviated term, the substantial benefits are significant, such as reducing environmental pollution and accelerating the transition to a zero-carbon economy. It is vital to note that Chinese college students represent a vast social group.

6. Conclusion and policy implications

6.1. Conclusion

This study aimed to investigate whether and how AI and VR can help college students widen their green sense and play a part in firsthand experiences of environmental sustainability. Four hundred students from distinctive regions and majors participated in this research. The results indicate that integrating AI and VR into environmental education provides the potential to increase student participation significantly. Both AI and VR display the potential to improve atmospheric comprehension, thereby inspiring more individuals to participate in environmental initiatives. The study also revealed that environmental awareness partially mediated the impact of AI on activism while it fully mediated the impact of VR on activism. This suggests that while both technologies positively affect environmental activism, VR is particularly effective in reinforcing climate education and increasing confrontation in environmental initiatives. Enriching college students' environmental awareness and obligation by incorporating AI and VR, which is a novel environmental teaching and outreach programs. The findings of this study hold significant implications for policymakers and educators.

Several caveats should be considered, even though this research gave valuable insights into the function of AI and VR in raising environmental consciousness and action among university students. It should be noted that the research was purely carried out in one area of China. Therefore, the results may not apply to other locations or nations. The research may have had less statistical weight because of its small sample size. Additionally, response bias and social desirability bias remain possible issues since the data collected is self-reported. Conclusively, other possible elements that may impact environmental awareness and activism were not examined in the research; as an alternative, the emphasis was placed merely on the function of AI and VR. Despite these caveats, the work does point the way toward some fascinating intended research. It would be profitable to repeat this research in other locations and nations to see whether the results also hold up there, which is necessary. To significantly strengthen the reliability and validity of the findings, forthcoming studies should expand the sample size and use more rigorous research methodologies, such as experimental designs or longitudinal investigations. In addition to corroborating the reliability of self-reported data, it may be advantageous to employ objective measurements of environmental knowledge and activism, such as energy use or membership in environmental groups. Subsequent research should also investigate other elements, such as social impact, peculiar beliefs, and cultural norms, that may contribute to increased environmental consciousness and activity. Finally, research on the efficacy of various AI and VR interventions, such as immersive VR simulations or individualized AI chatbots, would be welcome to raise environmental consciousness and activism among university students.

6.2. Policy implications

Given the significant and widespread impact of AI and VR on education, the keen interest of Chinese college students in these technologies, and their urgent desire to develop their environmental literacy through these revolutionary technologies, they can contribute to China's sustainable development and zero-carbon economy. Considering this national context, based on existing research findings, it is reasonable to emphasize the importance of policy support from the Chinese government and the Ministry of Education. Before all else, China accepts many cutting-edge high-tech companies; virtual reality products are currently active in the market. However, most of them are inclined toward entertainment and are often expensive. Through government policy support and procurement, selecting 3–5 universities as pilot institutions for better procurement and deployment is possible. The Ministry of Education should express widespread support and attention to the AI and VR classroom teaching performance in top-tier universities, accompanied by financial aid. Additionally, it is essential to carry out promotional activities among college students. Organizing large-scale competitions related to AI and VR for college student associations can fortify students from various grades and majors to participate and cultivate their sustainability literacy. This presents opportunities and challenges for companies and stakeholders involved in AI and VR. Companies can collaborate with the government and schools to regularly conduct classroom teaching activities on AI and VR, providing free equipment and teacher training to enlarge their corporate image and reputation, gaining a competitive advantage. The development of relevant companies can also address the employment issues of Chinese college students, launching a virtuous cycle. For university teachers, this is a captivating and enjoyable experience. Universities can prioritize the training of junior and middle-aged teachers, provide policy support, and naturally and reasonably introduce relevant conservancy of nature concepts and environmental action guidance in their respective fields, guiding college students to progress continuously toward a more environmentally friendly and sustainable future.

Ethics approval

No ethical approval was necessary for this study.

Consent to participate

All participants in this study consent to participation.

Consent for publication

All authors consent to this publication.

Authors' contributions

All authors contributed to the study's conception and design. **FeiFei Cao Yirong Jian** performed material preparation, data collection, and analysis. The first draft of the manuscript was written by **FeiFei Cao Yirong Jian**. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Declaration of competing interest

The authors have no relevant financial or non-financial interests to disclose

Data availability

The datasets used in this study are available from the corresponding author upon reasonable request.

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