

Systematic review of research on reality technology-based forest education

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Abstract. This systematic review explores the effectiveness of reality technology programs, such as augmented reality (AR) and virtual reality (VR), in enhancing forest education. By evaluating 13 selected studies from various academic databases, this research examines both the cognitive and affective outcomes of incorporating reality technologies into forest-related educational programs. The findings reveal that AR and VR significantly improve learning experiences by fostering deeper cognitive understanding and emotional engagement with forest environments and ecological concepts. Specifically, augmented reality was found to be highly effective in facilitating interactive, two-way communication, making learning more accessible and engaging for students. Additionally, virtual reality programs offered immersive experiences that enhanced participants' emotional connection to the subject matter. Both technologies contributed to overcoming traditional barriers in forest education, such as geographic limitations and resource constraints. The cognitive effects were reported in 90% of the studies, while affective benefits were evident in 100% of the cases. This review underscores the transformative potential of reality technology in making forest education more dynamic, inclusive, and effective, providing valuable insights for educators and researchers looking to further explore the integration of AR and VR in educational settings. These findings offer a solid foundation for future research and the practical application of reality technologies in environmental education.

1 Introduction

Forests play a pivotal role in combating the climate crisis due to their capacity to absorb carbon dioxide and regulate global ecosystems. International efforts, such as the 2015 Paris Climate Agreement, have highlighted the significance of forest preservation and sustainable forest management in addressing climate change [1]. Nations like South Korea have reinforced these global initiatives by setting ambitious targets for carbon neutrality by 2050, thereby emphasizing the critical need for ecological education focused on sustainability [2]. The importance of educating citizens about the environment, particularly forests, has been enshrined in policies such as the 2021 revision of the Framework Act on Education in

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Korea. This act mandates ecological transformation education for all citizens to better equip them with the knowledge and attitudes necessary to confront climate challenges [3].

Forest education, by definition, refers to experiential learning activities that allow individuals to understand the multifaceted value of forests and engage in practices that promote forest sustainability. This education is not merely theoretical but highly experiential, allowing participants to engage with forests directly, using sensory experiences to develop a deeper ecological sensitivity [4, 3]. Research has consistently shown that forest education has substantial positive effects across different age groups, enhancing social skills, emotional regulation, and environmental awareness, particularly in children and adolescents [5, 6]. Additionally, forest experiences have been linked to improved health outcomes and greater environmental sensitivity, making forest education a valuable tool for fostering a more environmentally conscious society [7, 8].

Despite the clear benefits of forest education, accessibility remains a significant barrier, particularly due to urbanization, the COVID-19 pandemic, and logistical constraints such as transportation and geographical distance [9]. These factors have resulted in decreased participation in forest education programs, particularly in South Korea, where participant numbers dropped by 50% between 2019 and 2020 [10]. Furthermore, practical limitations related to weather, seasonal restrictions, and accessibility to forest locations have made it challenging for many to engage in traditional forest education [9].

To address these challenges, reality technologies such as augmented reality (AR) and virtual reality (VR) have emerged as promising alternatives for forest education. Reality technologies allow users to simulate real-world experiences in a controlled, virtual environment, thereby overcoming many of the physical barriers associated with traditional outdoor learning [11]. Through the use of AR/VR, individuals can explore otherwise inaccessible forest locations, interact with forest ecosystems during different seasons, and participate in immersive educational experiences, all while remaining in a safe indoor environment [12]. These technologies offer the potential to significantly expand the reach and impact of forest education by making it more accessible to a broader audience.

However, despite the growing interest in integrating reality technology into education, particularly for subjects like environmental science, there is a lack of comprehensive reviews that systematically evaluate the effectiveness of these technologies in forest education [13, 14]. While several studies have examined the educational benefits of AR and VR in different contexts, few have focused specifically on their application in forest-related education, leaving a critical gap in the literature [15, 16].

1.1 Purpose of the study

This study seeks to address this gap by conducting a systematic review of the existing research on the use of reality technologies in forest education. The primary aim is to assess the cognitive and affective outcomes associated with the use of AR and VR in forest education, providing a clearer understanding of how these technologies can enhance the learning experience. Additionally, the study examines the current status and trends in the use of reality technology in forest education, identifying key areas where these technologies have been successfully integrated and highlighting areas that require further exploration. By providing a comprehensive analysis of the literature, this research aims to offer insights into the potential of reality technologies to overcome barriers related to accessibility, thereby promoting more inclusive and engaging forest education practices.

This research is particularly important in the context of the increasing emphasis on ecological education in the face of global climate challenges. As forests become central to climate action strategies, it is imperative to explore innovative educational tools that can

broaden public access to forest education. Reality technologies, with their ability to simulate real-world experiences in a controlled environment, hold promise for enhancing both the reach and effectiveness of forest education. Through this review, we aim to contribute to the growing body of knowledge on how technology can be leveraged to foster a more ecologically informed and engaged society.

2 Method

This study employed a systematic review methodology to evaluate the current state of intervention research and its effectiveness in applying reality technology (AR/VR) to forest education programs. The primary focus was to analyze the cognitive, affective, and psychological outcome variables within the selected studies.

2.1 Protocol and registration

The literature selection process followed the guidelines of PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) [17]. The search and selection process was structured using the Population, Intervention, Comparison, Outcome, and Study Design (PICOS) framework to ensure the comprehensive identification of relevant studies. Articles written in English and Korean were included, and bias in the studies was assessed using the ROBINS-I tool, which evaluates risk in nonrandomized controlled studies.

2.2 Eligibility criteria (PICOS)

The inclusion criteria were developed based on the PICOS framework to ensure the relevance and quality of the selected studies. Eligible studies were required to focus on forest education interventions utilizing reality technology. The intervention had to involve the use of virtual technologies aimed at fostering knowledge, skills, and attitudes about forest ecosystems and nature. Studies that involved biochemistry, nursing, or medical education were excluded. Additionally, only studies with quantitative evaluations of cognitive or affective learning outcomes were considered, while qualitative-only assessments and studies that lacked educational performance evaluations were excluded.

2.3 Search strategy

A comprehensive search of multiple academic databases, including ERIC, Web of Science, Scopus, PubMed, and ProQuest, was conducted. The search targeted publications between June 2022 and May 2024, focusing on keywords related to reality technology (e.g., "virtual reality," "augmented reality," "mixed reality"), forest education, and educational outcomes (e.g., "learning outcomes," "cognitive effects"). A manual search was also performed by reviewing reference lists from selected papers (Figure 1).

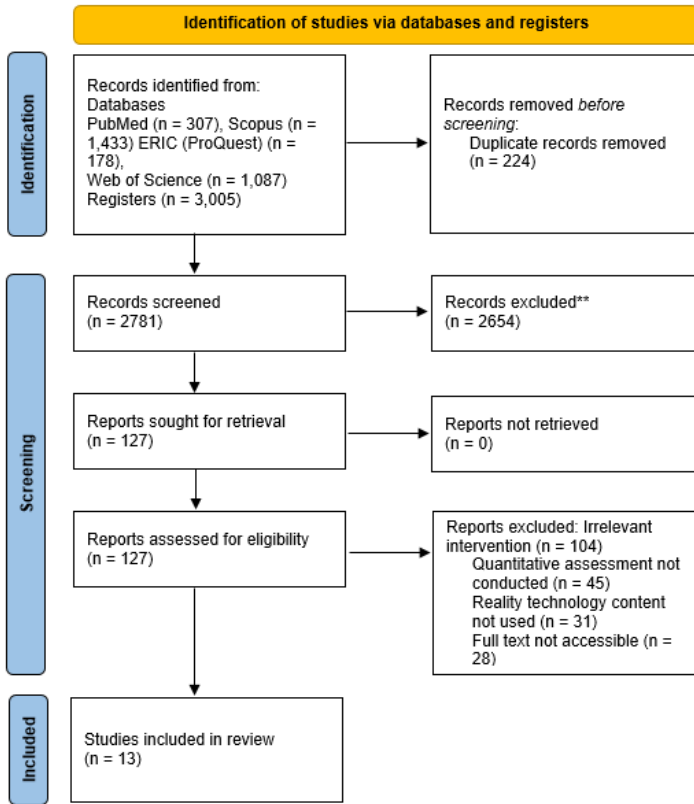


Fig. 1. Flow diagram.

2.4 Study selection

The search yielded 3005 articles across all databases, of which 294 duplicates were removed, leaving 2781 unique studies. After a preliminary screening based on titles and abstracts, 2654 studies were excluded. Two reviewers independently reviewed the full texts of the remaining 127 studies, further narrowing the selection down to 13 final papers that met all inclusion criteria. Discrepancies in the assessment were resolved through discussion with a third reviewer (Table 1).

Table 1. Main characteristics of the included studies.

Study	Country	Participant Group	Intervention (AR/VR)	Duration (mins)	Control Group	Outcome Measure	Study Design	Education Setting
Tosti H.C. Ching [18]	Taiwan/China	Elementary school students (n=29)	AR (Mobile device)	120	Traditional (mobile)	Custom-designed quiz (), ARCS () quiz, experiential	Pre-test and post-test	School campus (outdoor)

						al activity survey (Engagement, Challenge, Interest, Competency)		
Tien-Chi Huang [19]	Taiwan/China	Middle school students (n=21)	AR (Mobile device)	Not reported	Traditional	Custom-designed quiz (+), experiential activity survey (Engagement, Challenge, Interest, Competency)	Pre-test and post-test	Botanical garden (outdoor)
Rong-Chi Chang [20]	Taiwan/China	Elementary school students (n=27)	AR (Computer)	30	Video-based	Custom-designed quiz (after class (+), delayed (*))	Pre-test and post-test	Classroom (indoor)
Wernhuar Tarng [21]	Taiwan/China	Elementary school students (n=28)	AR with GPS (Mobile)	Not reported	Home-based traditional	Custom-designed learning outcome quiz (*), attitude survey (+)	Pre-test and post-test	School campus (outdoor)
Kuo-Liang Ou [22]	Taiwan/China	Adults (n=80)	VR (HMD/Computer)	Not reported	Traditional	Custom-designed learning outcome quiz (*)	Pre-test and post-test	Classroom (indoor)
Kuo-Liang Ou [23]	Taiwan/China	Middle school students (n=42)	VR (Mobile, 360° panorama)	Not reported	Traditional	Learning outcome quiz (), <i>motivation survey</i> ()	Pre-test and post-test	Classroom (indoor)
Yu-Cheng Chien [24]	Taiwan/China	Elementary school students (n=35)	AR (Mobile device)	35	Printed material	Custom-designed quiz (*)	Pre-test and post-test	School campus (outdoor)
Emmanuel Fokides [25]	Greece	Elementary school students (n=49)	VR (Mobile device)	90	Website	User experience survey: Fun/enjoyment (), <i>motivation</i> (), ease of use (*)	Pre-test and post-test	Classroom (indoor)
Kyra	Singapore	Adults	AR (Mobile)	Not	Not	Custom-	Pre-	Real-

Wang [26]	e	(n=85)	device)	report ed	reporte d	designed quiz (+)	test and post-test	world (outdoor)
Juan Garzon [27]	USA	Adults (n=40)	AR (Mobile device)	25	Traditi onal	Custom-designed quiz (+), IMMS (*)	Pre-test and post-test	Agritour ism farm (outdoor)
Emmanuel Fokides [28]	Greece	Middle school students (n=263)	AR (Mobile device)	120	Traditi onal	Custom-designed quiz (), <i>user experience survey: Fun/enjoyment</i> (), <i>motivation</i> (), <i>ease of use</i> ()	Pre-test and post-test	Classro om (indoor)
Engagement: Eng.; Challenge: Chal.; Interest: Int.; Competency: Comp.; ARCS: Attention, relevance, confidence, satisfaction. *: Statistically significant result; +: Non-significant but positive outcome. Educational settings varied across school campuses, botanical gardens, classrooms, and real-world environments, with AR and VR technologies facilitating learning. The studies employed a pre-test and post-test design to measure the cognitive and affective impacts on learners.								

2.5 Data extraction

Data were extracted by two independent authors using a standardized extraction process to ensure consistency and objectivity. Key data points included the publication year, country, participant characteristics, intervention duration, reality technology used, and cognitive and affective outcomes. Interventions were categorized based on their use of reality technology in forest education, and results were divided into cognitive and affective domains, with the percentage of significant positive outcomes calculated for each domain.

2.6 Quality assessment

The methodological quality of the selected studies was evaluated using the ROBINS-I tool, focusing on potential biases in nonrandomized controlled trials. The assessment covered biases related to confounding, participant selection, intervention classification, and outcome measurement. Each study was assigned a bias level ranging from "low risk" to "critical risk," following the Cochrane Handbook's recommendations. Two authors independently assessed the risk of bias across all seven domains, and disagreements were resolved through consensus.

This systematic review approach ensured a rigorous and thorough evaluation of the literature on the use of reality technology in forest education, providing reliable insights into its cognitive and affective effectiveness.

3 Results

3.1 Study characteristics

This systematic review included 13 studies focusing on the application of reality technology in forest education. The overall participant count across these studies was 938, with 409 participants experiencing reality technology interventions. The participant size for each study varied from 21 to 263 individuals. Of the total, seven studies were conducted with elementary school students, while three targeted middle school students and three involved adults. All participants were characterized by general demographic features, indicating that the findings could be broadly applicable [19, 20].

The intervention programs employed reality technology content designed to teach participants about the environment, plants, animals, and geological features found in forest ecosystems. In every study, the technology was used more than once to facilitate learning. A detailed analysis of the educational content reveals that seven studies addressed topics related to terrestrial ecosystems, two focused on geological aspects, and four concentrated on wetland and pond ecosystems, including various species and plant life. The terrestrial ecosystem topics included reforestation, plant growth, insect life cycles, endangered species, and the physiology of plants [22]. Geological subjects examined rock formation, weathering, and erosion processes, while wetland education focused on the ecological relationships in aquatic environments [27].

In terms of the frequency of interventions, most studies utilized a single instance of reality technology, with only two studies conducting multiple interventions. The duration of these interventions ranged from 25 minutes to 120 minutes, with the average session lasting approximately 72 minutes. The analysis found no significant correlation between the duration of interventions and their overall effectiveness. Two studies reported intervention durations of 120 minutes, one lasted for 90 minutes, three for 60 minutes, and the remainder had sessions under 60 minutes [19, 23].

Five of the studies were conducted indoors (e.g., classrooms), while the other five took place outdoors in environments like school campuses, national parks, and gardens. No notable difference in learning outcomes was observed between indoor and outdoor settings. However, outdoor training programs tended to blend physical spaces with virtual environments, which enhanced the educational experience by making the learning process more interactive and dynamic [25].

Augmented reality (AR) emerged as the most commonly used technology across the studies. Of the 16 interventions assessed, 11 employed AR, while the rest utilized immersive virtual reality (VR). Various types of software were used in these studies. One study utilized a 2D interface, another incorporated 360-degree panoramic images, and 14 employed 3D imaging techniques. Most of the software was custom-developed for the studies, with the exception of two that used commercially available programs. The educational content designed with reality technology simulated forest environments, allowing participants to actively engage by interacting with the material through touch screens or AR markers, thus providing an immersive learning experience [21, 24].

All 13 studies employed a pre-posttest design, enabling researchers to assess cognitive and affective outcomes both before and after the interventions. Due to the non-randomized nature of the studies, the ROBINS-I tool was applied to evaluate the risk of bias. Geographically, most of the studies were conducted in Taiwan or China (eight studies), followed by the United States (two studies), Greece (two studies), and Singapore (one study). Interest in using reality technology for forest education has grown since the late 2010s, with six studies published after 2020, reflecting the increased attention this field has garnered in recent years [22, 28].

In terms of academic fields, eight of the reviewed studies were published in educational journals, particularly in the realm of digital education and technology. Four studies were published in journals dedicated to nature and environmental education, underscoring the

interdisciplinary nature of this research. As the integration of reality technology into educational contexts continues to grow, the results of these studies provide valuable insights into its practical applications and efficacy in forest education [27].

3.2 Outcomes

The results of the studies were categorized into cognitive and affective domains based on the educational target areas. Previous studies have classified cognitive domains to include knowledge and the definition of attitude functions, while affective domains have included various psychological aspects such as attitudes, interests, and values [31, 32]. For this systematic review, the outcomes were analyzed using this classification: cognitive areas were assessed through quizzes and knowledge tests, while affective areas focused on emotions, motivation, and engagement. The psychological domain was excluded as it did not show significant effects in these studies [33, 34].

3.2.1 Cognitive Domain

All 13 studies assessed the impact of reality technology-based forest education on cognitive outcomes. The primary measurement tools were quizzes related to the educational content, and these tools were self-produced for each study. The cognitive results were generally measured immediately after the intervention, with some assessments delayed for follow-up analysis. A total of 20 tests were administered across the studies. Nine of these studies reported immediate cognitive improvement following the intervention, indicating that reality technology enhances cognitive learning outcomes in forest education [19, 24, 25, 27].

In terms of participant demographics, seven of the studies were conducted with elementary school students, comprising 37.5% of the studies, while five studies (31.25%) focused on middle school students, and four studies (25%) were aimed at adults [20, 28]. The most commonly used devices were mobile phones and tablets, which were employed in 10 studies. Two studies used computers, and one study used a head-mounted display (HMD) for immersive virtual reality [23, 29].

Six studies included control groups that followed traditional education methods, such as lectures or textbooks. These control groups were compared with intervention groups using augmented reality (AR) or virtual reality (VR) tools. In one study, participants in the intervention group received guidance through AR, while the control group used traditional self-study methods [25]. Other control groups received education through mobile devices without AR, web pages, or video-based instruction [19, 27]. Across these comparisons, the cognitive outcomes for the intervention groups were consistently higher, showcasing the positive influence of reality technology on forest education [16].

3.2.2 Affective Domain

The affective domain refers to emotional and psychological responses such as motivation, attitude, and engagement. Out of the 13 studies, 10 evaluated affective outcomes, particularly focusing on how reality technology impacted students' and participants' emotional engagement with the content. The analysis showed that forest education using AR or VR led to significantly higher levels of motivation and engagement compared to traditional methods [33, 34].

Participants reported greater enjoyment and a more profound connection with nature when using reality technology. Additionally, studies showed that AR-based education fostered stronger environmental awareness and positive attitudes toward nature

conservation [23]. These affective responses are crucial in environmental education, as they help create long-lasting attitudes and behavioral changes toward nature and conservation efforts [28, 27].

3.2.3 Cognitive Domain

Eight studies indicated that the use of reality technology in forest education had a more substantial effect on cognitive outcomes than traditional teaching methods [25, 27, 20, 28]. These studies showed that the cognitive impact of using augmented reality (AR) and virtual reality (VR) in forest education was significantly higher when compared to the traditional use of printed materials, web pages, or mobile devices without AR [19, 23]. For example, one study demonstrated that using virtual ecosystems through reality technology had a greater cognitive effect than traditional methods [24].

However, there were instances where reality technology did not show immediate cognitive benefits. In one study, general teaching methods and AR-based education were compared, and although no significant cognitive improvement was observed immediately after the class, significant improvement was noted at a later stage [27]. Reality technology was also shown to outperform other educational technologies such as videos and mobile devices [19, 25]. Additionally, both self-learning using AR and commentator-guided sessions yielded strong cognitive results [25]. Therefore, it can be concluded that reality technology significantly enhances cognitive learning in forest education when compared to conventional pedagogical approaches.

3.2.4 Cognitive Domain Categorized by Intervention

The cognitive outcomes were further categorized based on educational age, type of reality technology used, location of education, and duration of educational sessions. In terms of educational age, six studies (75%) reported significant cognitive effectiveness among elementary school students, while six studies (85.71%) found cognitive benefits among middle school students. For adults, three studies (60%) observed positive cognitive outcomes. In addition, although these improvements were not always statistically significant, five studies reported raised cognitive scores, with two studies focusing on elementary school students (25%), one on middle school students (14.29%), and two on adult participants (50%) [22, 27].

When categorizing by technology type, AR was the most frequently used technology across the studies. For instance, AR-based interventions consistently showed stronger cognitive effects compared to traditional methods and other technologies like videos [29]. Moreover, the duration of the intervention also played a role. Studies that implemented longer sessions, generally 60 minutes or more, tended to report more significant cognitive gains. This highlights that extended exposure to AR and VR tools allows learners to engage more deeply with the content, further enhancing their cognitive understanding [19, 25].

In conclusion, the studies reviewed suggest that reality technology not only outperforms traditional teaching methods but also provides enhanced cognitive learning across different age groups, educational settings, and technologies. Reality technology's potential to revolutionize forest education, particularly in terms of cognitive development, is evident from these findings. In total, 10 of the 13 reviewed studies reported significant results in the affective domain, particularly regarding factors such as interest, motivation, and engagement [19, 25]. These results underscore the effectiveness of AR-based interventions in enhancing emotional connections to the educational material. The sub-areas examined included "enjoyment" (often referred to as interest), "motivation," "recognition," "participation," "attitude," and "challenge" [21, 27]. The ARCS model (Attention,

Relevance, Confidence, and Satisfaction) was one of the most frequently used tools for measuring these affective outcomes [34]. Custom-designed tools were also used to gauge these emotional factors, particularly in middle school students, who demonstrated the highest level of engagement (55.65%) compared to elementary students (33.33%) and adults (11%) [25, 26].

3.2.5 Affective Domain

The affective impact of AR was consistently higher across studies that employed mobile devices as the primary technology platform [25, 18]. These studies showed that AR's interactive and immersive features were crucial in engaging students emotionally. Virtual Reality (VR), though utilized less frequently, also produced significant results, particularly when combined with interactive elements that allowed students to explore virtual forest ecosystems [22, 26]. The immersive nature of VR enabled students to engage more deeply with the content, increasing motivation and interest in forest-based educational topics [25].

Furthermore, the studies revealed that middle school students experienced the most significant affective gains, particularly in terms of engagement and motivation [27]. This aligns with the developmental stage of middle school students, where curiosity and exploratory learning play a significant role in emotional engagement [19]. In conclusion, AR and VR technologies were shown to significantly enhance emotional engagement, particularly in forest education. This finding was especially prominent in middle school students, where motivation and engagement were highest due to the interactive nature of the technology [27]. The use of AR in particular helped create a more interactive and emotionally engaging learning environment, which can be critical in forest education and potentially other fields [25]. Future research should explore how these affective benefits can be expanded to other educational contexts and across different age groups, building on the strong outcomes demonstrated in these studies.

The effectiveness of augmented reality (AR) and virtual reality (VR) technologies in enhancing the affective domain, particularly in motivation and interest, was a notable finding in this systematic review. In total, 10 studies demonstrated significant results in the affective domain [29, 24, 19, 27]. Key areas assessed included "motivation," "interest," "perception/recognition," "participation," and "attitude"—with "motivation" and "interest" being the most frequently measured affective components [19, 26].

Motivation was assessed in nine studies, with six demonstrating statistically significant improvements [29, 24, 27]. AR, in particular, appeared to be more effective at increasing motivation when compared to traditional learning methods, mobile devices without AR, and video-based training [29, 25]. Conversely, one study noted improved motivation, but without statistical significance [25].

Interest was a crucial aspect in four studies, where AR demonstrated superiority over traditional methods such as textbooks and guide maps [27, 24]. Studies that focused on "perception/recognition" also showed positive results, particularly in studies employing AR mobile devices [25]. Participation and attitude were evaluated in two and one study, respectively, with one study finding participation significantly improved through AR-based interventions [29].

Interestingly, challenge was not found to be effective in the two studies that assessed it, suggesting that AR might not enhance all aspects of affective engagement equally [24]. Most studies comparing AR interventions with traditional teaching methods (lectures, textbooks, printed materials) demonstrated that AR was significantly more effective in improving emotional engagement and motivation [25].

3.2.6 Affective Domain by Demographic Group and Setting

The categorization of affective outcomes by demographic groups revealed that middle school students experienced the most significant improvements in affective outcomes. Specifically, 60% of the interventions with middle school students showed statistically significant results in motivation and engagement [19]. Meanwhile, 55.56% of elementary school interventions reported significant improvements, although two cases were not statistically significant [25]. AR interventions appeared to be particularly beneficial for elementary and middle school students in fostering engagement, interest, and motivation, more so than for adult participants [27].

In terms of study environment, all 10 indoor studies reported positive effects in the affective domain, while outdoor interventions were less effective, with only eight of 18 outdoor interventions demonstrating significant results [29, 27]. This discrepancy might be attributed to the fact that outdoor interventions often involve a mix of virtual and real-world experiences, which could introduce additional variables affecting participants' engagement levels.

In summary, AR consistently outperformed traditional teaching methods in improving motivation, interest, and engagement across various demographic groups and educational settings. The findings suggest that AR and VR can be particularly effective tools for enhancing the affective aspects of learning in forest education, with AR showing more consistent results. However, the effectiveness of AR and VR in the affective domain may vary depending on the demographic group, the specific affective component measured, and the educational environment in which the intervention takes place.

3.2.7 Other Effects

In addition to cognitive and affective domains, several studies analyzed the psychological impact of reality technology in forest education. These studies assessed participants' emotional responses, revealing a mix of positive and negative emotions [24, 22]. Specifically, four interventions were analyzed across two studies, focusing on the psychological domain, with data collected through self-produced tools modeled after the Guide in Management of Analysis (1997) or an emotion self-assessment questionnaire [24, 22, 30].

Of these, only one study reported statistically significant psychological changes after participants engaged in forest-based education using AR. In this case, the psychological effect was detected in participants who received AR-based commentator guidance during self-learning, in contrast to the control group who used traditional learning methods [24]. However, when self-learning was conducted without commentator guidance, no significant psychological differences were observed, although there was a noted improvement in overall emotional engagement [24].

In studies utilizing head-mounted displays (HMD) and desktop virtual reality (VR), anxiety levels were measured as part of the psychological effects. Although both HMD VR and desktop VR resulted in lower anxiety levels, the findings were not statistically significant [22]. Nevertheless, these results are promising, as they suggest that the use of VR in forest education does not induce high levels of anxiety, an often-cited concern regarding immersive technologies [30]. The low levels of anxiety reported highlight the potential for safely integrating VR into educational settings, particularly in the context of forest education [22].

4 Discussion and Conclusions

This systematic review explored the cognitive and affective impacts of reality technology, including augmented reality (AR) and virtual reality (VR), in forest education. The findings highlighted significant improvements in both cognitive and affective domains, with middle school and elementary school students showing the most pronounced cognitive effects, aligning with prior research that emphasizes the importance of ecological knowledge acquisition at early education stages [26].

The studies reviewed showed that cognitive improvement was substantial, particularly in AR-based interventions, with 64.29% of AR studies ($n = 9$) and 100% of VR studies ($n = 4$) demonstrating significant cognitive effects. Most of the studies were conducted indoors, with 90% reporting cognitive enhancement, suggesting that reality technology is effective even when used outside natural environments [19, 27]. These findings indicate that forest education utilizing AR and VR can compensate for the limitations posed by geographical or environmental constraints, supporting the idea that technology-based interventions can be as effective indoors as they are outdoors. Interestingly, the usage time of reality technology did not significantly affect the cognitive outcomes, further confirming the adaptability of these technologies in educational settings [18].

In the affective domain, middle school students exhibited the greatest improvement, with 60% of studies ($n = 9$) demonstrating significant positive impacts on motivation and interest. While the sample size for adults was smaller, the affective results were still noteworthy. Studies measuring affective outcomes reported AR as particularly effective in increasing student engagement and motivation. In fact, AR outperformed traditional learning methods in motivating students and maintaining their interest [24]. The immersive nature of AR likely contributed to this, as it allows for interactive learning, which is considered more engaging than passive traditional methods [25].

Research on reality technology in education is expanding, particularly in East Asia. The use of AR, in particular, has grown due to its accessibility and flexibility in both cognitive and affective domains. AR facilitates two-way interaction and real-time feedback, making it highly effective for educational purposes. As reality technology becomes more integrated into global educational practices, its role in forest education will likely continue to expand. However, further studies are needed to verify these findings on a broader, more global scale. While this review included a large number of studies from Taiwan, future research should incorporate data from more diverse geographical regions to ensure the global applicability of the findings [23].

The methodological quality of the studies reviewed presented some limitations, particularly regarding the self-reporting of outcomes. Studies relying on self-reported data may introduce bias, as participants are aware of the intervention they are receiving. This can skew the results toward more favorable outcomes [21]. To mitigate this risk in future research, using high-reliability, objective measures in evaluating the cognitive and affective impacts of reality technology in education is essential. Despite these challenges, the bias introduced did not appear to have a substantial impact on the overall conclusions of this review.

This systematic review provides the first comprehensive analysis of the effectiveness of reality technology in forest education, confirming that both AR and VR significantly improve cognitive and affective outcomes. The findings suggest that reality technology can bridge gaps in accessibility, enabling more students to participate in forest education. By reducing barriers related to physical access, such as distance or environmental factors, AR and VR offer inclusive and flexible learning solutions that can be adapted to various educational contexts.

As expectations for the use of reality technology in education grow, it is important to continue researching its long-term effects and address concerns related to the psychological impact, such as potential increases in anxiety when using VR [22]. Further research should

also examine the scalability of these findings beyond East Asia, ensuring that they are applicable to different educational systems worldwide. With continued exploration, reality technology holds great promise for enhancing both cognitive and affective learning outcomes in forest education and beyond.

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