Virtual Reality Media in Elementary School IPAS Ecosystem Learning: Needs and Critical Scientific Thinking

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Abstract : *Learning ecosystem topics in elementary Natural and Social Sciences (IPAS) is challenging because ecological processes are difficult to visualize through conventional media. This study aimed to identify students' and teachers' needs for Virtual Reality (VR) media and examine students' critical scientific thinking before and after VR-based learning. A quantitative design combining needs analysis and a one-group pretest–posttest involved 64 fifth-grade students and six teachers. Data were collected through tests and questionnaires and analyzed using descriptive statistics, normalized gain (N-gain), and the Wilcoxon signed-rank test. Results showed that 60.9% of students struggled to visualize ecological relationships, 84.4% were interested in VR, and only 9.4% had used VR devices. Teachers reported very high needs for VR media (3.67/4.00) and supporting features (3.80/4.00). Students' mean scores increased from 75.3 to 87.3, with a moderate N-gain of 0.49 ($p < 0.001$). Additionally, 59 of 64 students improved. These findings suggest that VR-based learning is needed and has potential to support critical scientific thinking, although the one-group design limits causal conclusions.*

Keywords : *Virtual Reality, Critical Scientific Thinking, Needs Analysis, IPAS Learning, Ecosystem*

Abstrak : Topik ekosistem pembelajaran di Ilmu Alam dan Sosial (IPAS) dasar sangat menantang karena proses ekologi sulit divisualisasikan melalui media konvensional. Studi ini bertujuan mengidentifikasi kebutuhan siswa dan guru akan media Realitas Virtual (VR) serta menelaah pemikiran ilmiah kritis siswa sebelum dan sesudah pembelajaran berbasis VR. Desain kuantitatif yang menggabungkan analisis kebutuhan dan ujian pra-sesudah satu kelompok melibatkan 64 siswa kelas lima dan enam guru. Data dikumpulkan melalui tes dan kuesioner serta dianalisis menggunakan statistik deskriptif, normalisasi gain (N-gain), dan tes Wilcoxon signed-rank. Hasil menunjukkan bahwa 60,9% siswa kesulitan memvisualisasikan hubungan ekologis, 84,4% tertarik pada VR, dan hanya 9,4% yang pernah menggunakan perangkat VR. Guru melaporkan kebutuhan sangat tinggi untuk media VR (3,67/4,00) dan fitur pendukung (3,80/4,00). Skor rata-rata siswa meningkat dari 75,3 menjadi 87,3, dengan kenaikan N sedang sebesar 0,49 ($p < 0,001$). Selain itu, 59 dari 64 siswa mengalami perbaikan. Temuan ini menunjukkan bahwa pembelajaran berbasis VR diperlukan dan berpotensi mendukung pemikiran ilmiah kritis, meskipun desain satu kelompok membatasi kesimpulan kausal.

Kata Kunci : Realitas Virtual, Pemikiran Ilmiah Kritis, Analisis Kebutuhan, Pembelajaran IPAS, Ekosistem

INTRODUCTION

Ecosystem is a fundamental topic in Natural and Social Sciences (IPAS) education at the elementary school level, as it requires students to understand the relationships between biotic and abiotic components, energy flow, and interactions among living organisms. However, ecosystem concepts, including food chains, food webs, and material cycles, can be challenging for elementary school students because they involve interconnected processes that are not always directly observable. Kuroru and Rahmah (2023) reported cognitive difficulties among elementary school students in understanding ecosystem concepts, highlighting the need for learning approaches that support meaningful conceptual understanding rather than memorisation. Beyond conceptual knowledge, ecosystem learning should also develop critical scientific thinking, including the ability to observe phenomena, analyse cause-and-effect relationships, interpret evidence, evaluate human activities, and draw conclusions. These competencies are important for helping students understand environmental processes and develop awareness of environmental responsibility.

One challenge in ecosystem education is the limited capacity of conventional learning media, such as textbooks, two-dimensional images, and static dioramas, to represent dynamic ecological processes and interactions. To address this limitation, researchers have developed technology-based learning media, including augmented reality (AR), to provide more interactive visualisations of ecosystem concepts. Studies by Cahyani et al. (2025) and Maziyah and Zumrotun (2025) illustrate the application of AR in developing elementary school learning media on ecosystem topics. Nevertheless, visualisation alone may not be sufficient to support deeper understanding of complex ecological relationships. Learning media should enable students to explore ecosystems, observe interactions, and connect their observations with scientific explanations. This need provides a rationale for investigating immersive technologies, particularly virtual reality (VR), as an alternative approach to ecosystem learning.

Recent research supports the potential of immersive technologies in science education. A meta-analysis by Chen et al. (2026) found a positive, moderate effect of educational virtual environments, including VR, AR, and mixed reality, on science learning among K–12 students, with educational stage identified as a significant moderating factor. Similarly, Wu et al. (2020) reported positive learning outcomes associated with immersive VR using head-mounted displays across educational contexts. Durukan et al. (2020) also reviewed the use of VR in science education, highlighting its potential to provide experiences that are difficult to reproduce through conventional classroom instruction. In addition, research on virtual field trips indicates that immersive experiences can support learning when the instructional design is appropriately aligned with the subject matter and learning objectives (Makransky & Mayer, 2022; Petersen et al., 2020). These findings establish a theoretical and empirical basis for exploring VR as a medium for helping elementary school students understand ecosystem relationships through virtual exploration.

VR offers opportunities for students to explore simulated environments, observe interactions among ecosystem components, and investigate situations that may be difficult to access directly in real-world settings. Research by Cho et al. (2022) demonstrated that virtual environments can influence learning effectiveness, motivation, cognitive load, and group self-efficacy among elementary school students engaged in collaborative learning. In Indonesia, Herwin et al. (2022) examined a VR-based learning management system in elementary education, while Erviana and Sepriansyah (2024) investigated the effectiveness of VR media on primary school students' learning outcomes. These studies indicate the relevance of VR for elementary education, although the suitability of a particular implementation depends on the learning context, available devices, teacher readiness, and the characteristics of the content. Therefore, the development of VR media should begin with an understanding of students' learning needs and teachers' practical requirements rather than relying solely on the technological capabilities of the medium.

Despite these opportunities, immersive technology does not automatically improve learning outcomes. Makransky et al. (2019) found that adding immersive VR to a science laboratory simulation increased students' sense of presence but reduced learning performance. This finding highlights the importance of balancing immersion with appropriate instructional guidance. The Cognitive Theory of Multimedia Learning emphasises the need to design learning materials in ways that support meaningful processing of information (Mayer, 2024), while cognitive load theory highlights the importance of managing the demands imposed on learners' limited cognitive resources (Sulisworo et al., 2024; Zou et al., 2025). Accordingly, VR content should be designed with clear learning objectives, scientifically accurate representations, appropriate narration, guided activities, and assessment opportunities. These considerations are particularly important for elementary school students, whose learning needs require careful alignment between content complexity, instructional support, and the level of immersion.

Although previous studies have examined VR in science education, learning effectiveness, and elementary school contexts, further investigation is needed into how VR media for ecosystem learning should be aligned with the specific needs of students and teachers in Indonesian elementary schools. In particular, understanding students' preferred ecosystem environments, teachers' readiness, and practical barriers to implementation can provide a more relevant foundation for media development. Furthermore, evaluating students' critical scientific thinking before and after VR-based learning can provide preliminary evidence regarding learning-related changes in the implementation context. The novelty of this study lies in combining a needs analysis involving students and teachers with an evaluation of critical scientific thinking in the context of VR-based ecosystem learning within the IPAS subject. Rather than treating VR as a technology-led intervention, the study connects media development decisions with the actual learning context and the practical conditions of elementary school implementation.

Therefore, this study aims to identify students' and teachers' needs and readiness regarding VR media for ecosystem learning in elementary school IPAS education and to describe students' critical scientific thinking before and after VR-based learning. The needs analysis is intended to inform the design of VR content, while the learning evaluation provides preliminary evidence of students' performance in the implementation context. The findings are expected to support the development of contextually appropriate, accessible, and instructionally grounded VR media for ecosystem education. This study is important because effective integration of immersive technology requires not only technological innovation but also alignment with curriculum objectives, learner characteristics, teacher readiness, and evidence-based instructional design.

METHODS

This study employed a quantitative approach combining a needs analysis with a pre-experimental one-group pre-test–post-test design. The needs analysis aimed to identify students' and teachers' needs and readiness for Virtual Reality (VR) media in ecosystem learning within the Natural and Social Sciences (IPAS) subject, whilst the pre-test–post-test design was used to examine changes in students' critical scientific thinking before and after VR-based learning. The participants comprised 64 Year 5 primary school pupils from two parallel classes, V Al Qodr and V Al Maidah, with 32 pupils in each class, and six teachers who completed the teacher needs questionnaire. The research began with the administration of student and teacher questionnaires, followed by a pre-test, VR-based learning activities, and a post-test. The VR simulation presented forest and river ecosystems, including the effects of tree felling and waste pollution on ecosystem components. The specific school location and research period should be added based on the original research records.

Data were collected using a critical scientific thinking test and student and teacher questionnaires. The pre-test and post-test each comprised 10 stimulus-based essay questions covering the same ten indicators: observing and identifying problems, analysing cause-and-effect relationships, using evidence, analysing changes in ecosystem components, evaluating information or evidence, drawing conclusions, solving problems, relating evidence to spiritual values, evaluating human actions and decisions, and analysing or synthesising relationships between ecosystem components.

Test scores were reported on a scale of 0–100. The student questionnaire consisted of 17 closed-ended items and eight open-ended items addressing students' interests, learning difficulties, previous experience of VR, learning media, and learning needs. The teacher questionnaire comprised 37 statements rated on a four-point Likert scale, covering five areas: ecosystem learning conditions, the use of learning media, knowledge and experience of VR, the need for VR media, and desired VR features. Seven additional open-ended questions explored teaching difficulties, existing media, VR requirements, expected features, implementation barriers, and suggestions. Data were analysed using descriptive statistics, including means and standard deviations, alongside normalised gain (N-gain) to describe changes in test scores. The distribution of score differences was assessed using the Shapiro–Wilk test. As the results indicated a departure from normality ($p < 0.05$), pre-test and post-test scores were compared using the Wilcoxon signed-rank test at a significance level of 0.05. Closed-ended student responses were summarised using frequencies and percentages, whilst open-ended responses were categorised according to common themes. Teacher questionnaire data were analysed by calculating the mean for each item and section, then converting the results into indices and corresponding categories.

Several methodological limitations were considered when interpreting the findings. First, the one-group design without a control group limits the extent to which changes in test scores can be attributed exclusively to VR-based learning, as other instructional influences, maturation, and familiarity with the test format may also have contributed. Secondly, although the pre-test and post-test covered the same indicators, they used different stimuli, and their scores were not statistically equated. Thirdly, most pupils had no previous experience of VR, meaning that the novelty of the technology may have influenced their interest and engagement. Finally, only six teachers completed the questionnaire; therefore, their responses were interpreted descriptively and were not intended to support broad generalisations. These limitations were taken into account when interpreting the findings and considering their applicability to other educational settings.

RESULTS AND DISCUSSION

The results are presented in four parts: students' learning outcomes before and after learning (Subsection 4.1), students' needs and readiness for VR media (Subsection 4.2), teachers' needs and readiness (Subsection 4.3), and a discussion that integrates the three data sources into design implications (Subsection 4.4).

Pretest and Posttest Results

The Shapiro–Wilk test showed that the pretest and posttest scores of the combined group, and the score differences within each class, were not normally distributed ($p < 0.05$); therefore, the Wilcoxon signed-rank test was used. The mean score increased in both classes (Table 2). In V Al Qodr, the mean score rose from 76.7 to 88.3 (N-gain = 0.50), and in V Al Maidah from 73.9 to 86.4 (N-gain = 0.48). For the two classes combined (N = 64), the mean score rose from 75.3 to 87.3, an increase of 12.0 points (N-gain = 0.49, moderate category). The increase was significant in each class and in the combined group ($p < 0.001$), as shown in Table 2 and Fig. 2.

Table 2. Summary of pretest, posttest, and N-gain results by class

Class	n	Pretest M (SD)	Posttest M (SD)	Gain	N-gain	Category
V Al Qodr	32	76.7 (11.2)	88.3 (9.3)	11.6	0.50	Moderate
V Al Maidah	32	73.9 (13.2)	86.4 (9.8)	12.5	0.48	Moderate
Combined	64	75.3 (12.2)	87.3 (9.5)	12.0	0.49	Moderate

Note. M = mean; SD = standard deviation. N-gain was calculated from the class means. The Wilcoxon signed-rank test gave $p < 0.001$ for each class and for the combined group.

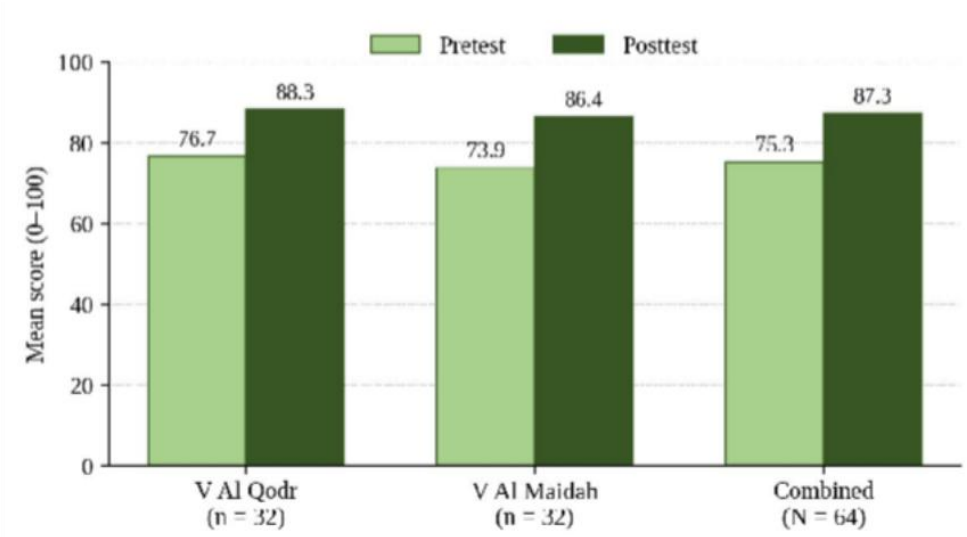


Figure 1. Mean pretest and posttest scores of the two classes and of both classes combined

At the individual level, 59 of the 64 students improved, five students showed no change (two of whom had already obtained the maximum pretest score of 100), and no student's score decreased. Among the 62 students whose pretest score was below 100, 19 students (30.6%) reached the high N-gain category, 27 (43.5%) the moderate category, and 16 (25.8%) the low category. The lowest-scoring students benefited most: all six students with a pretest score of 60 or below scored at least 70 on the posttest. Even so, 16 students remained in the low N-gain category, which indicates room for improvement. Because this study used a one-group design without a control group, the improvement after VR-based learning cannot be attributed to VR alone. The direction of the result is, however, consistent with prior studies reporting positive effects of immersive virtual environments on learning (Chen et al., 2026; Wu et al., 2020; Erviana & Sepriansyah, 2024).

Students' Needs for VR Media

Table 3 summarizes the closed-ended items of the student questionnaire. Most students liked IPAS and the ecosystem topic (85.9%) and were interested in the current way of learning (70.3%). However, 60.9% reported often or very often having difficulty imagining the relationship between living things and their environment, and only 65.1% found it easy to understand the topic from explanations or textbooks alone. Existing learning relied mainly on the textbook and the teacher's explanation (43.8%), followed by the whiteboard (21.9%), video (18.8%), and pictures or posters (9.4%) (item A2), and 71.9% said the textbook, whiteboard, or direct explanation was always or often used (item A3). Pictures in the textbook helped 75.0% of students, and 53.1% often or very often felt bored when learning relied only on the textbook and the teacher's explanation (item B4). Explanation as shown in Table 3.

Table 3. Student questionnaire results: learning conditions, need for media, and VR familiarity and interest

Code	Indicator	Top two options (%)	Valid N
A1	Likes IPAS/the ecosystem topic	85.9	64
A4	Interested in the current way of learning	70.3	64
A5	Finds it easy to understand from explanations/textbooks alone	65.1	63
B3	Textbook pictures help understand ecosystems	75.0	64

Code	Indicator	Top two options (%)	Valid N
B2	Often/very often has difficulty imagining the relationship between living things and the environment	60.9	64
C1	Wants more interesting media	85.9	64
C3	Interested in seeing ecosystems more realistically	79.7	64
C4	Technology helps understand ecosystems	79.7	64
D1	Has heard of/knows VR	34.4	64
D2	Has used a VR device	9.4	64
D3	Interested in using VR for the ecosystem topic	84.4	64
D4	VR makes learning more enjoyable	87.5	64
D5	Wants to see animals/plants/the environment through VR	84.4	64

Note. Percentages combine the two most favorable options of each item; for B2, the two most frequent options (very often and often); for D1 and D2, the share answering "yes" and "have used".

Students showed a clear need for more engaging media: 85.9% wanted more interesting media, 79.7% were interested in seeing ecosystems more realistically, and 79.7% agreed that technology helps them understand ecosystems (items C1, C3, and C4). When asked which medium they liked most, VR was the most frequent single choice (25.0%), ahead of educational games (20.3%), video (18.8%), animation (17.2%), and pictures (14.1%) (item C2). Students' familiarity with VR was low: only 34.4% had heard of VR and 9.4% had ever used a VR device (items D1 and D2). Nevertheless, 84.4% were interested in using VR for the ecosystem topic, 87.5% agreed that VR would make learning more enjoyable, and 84.4% wanted to see animals, plants, and the environment through VR (items D3–D5).

The open-ended answers pointed to what VR should show. The parts of the ecosystem topic that students found most difficult were examples of rice paddy and forest ecosystems (28.1%), the relationship between animals and their habitats (23.4%), and distinguishing biotic from abiotic components (20.3%) (item B1). The most common complaints about current learning were too much reading (32.8%) and unclear pictures in the textbook (23.4%) (item E2). If VR were used, students most often expected to explore a rice paddy ecosystem virtually (26.6%), to see the relationships between living things and their environment (20.3%), and to see animals and plants up close (18.8%) (item D6), and the activities they most wanted to try were observing animals and plants (29.7%), identifying biotic and abiotic components (21.9%), and an interactive quiz (21.9%) (item E4). Regarding readiness (item E5), 47 of 64 students (73.4%) were willing to use VR, although 25.0% said they needed to learn how to use the device first and 20.3% wanted teacher guidance, while another 25.0% were not yet sure because they had never tried it. Only one student (1.6%) was not willing before knowing the rules of use and safety.

Teachers' Needs for VR Media

Table 4 presents the mean score of each section of the teacher questionnaire. Teachers rated the need for VR media for the ecosystem topic (Section F, mean 3.67), the needed VR features (Section G, mean 3.80), and the use of learning media in IPAS (Section D, mean 3.55) as very high. The learning conditions (Section C, mean 3.23) and the teachers' knowledge and experience of VR (Section E, mean 2.75) were in the high category, with Section E the lowest of the five sections.

Table 4. Teacher *Note.* Index = mean divided by 4. Categories follow Subsection 3.2

Section	Items	Mean	Index	Category
C. Learning conditions of the IPAS ecosystem topic	8	3.23	0.81	High
D. Use of learning media	7	3.55	0.89	Very high
E. Knowledge and experience of VR	6	2.75	0.69	High
F. Need for VR media for the ecosystem topic	6	3.67	0.92	Very high
G. Needed VR features	10	3.80	0.95	Very high

Note. Index = mean divided by 4. Categories follow Subsection 3.2.

At the item level, teachers fully agreed (4.00) that students are more enthusiastic with audiovisual or interactive media, that teachers need alternative media for the ecosystem topic, and that interactive questionnaire results by section (scale 1–4, n = 6) media raises students' attention (items C7, C8, and D7). They also strongly agreed that concrete media are needed (C5, 3.67), that VR is needed to help students understand ecosystems (F1, 3.83), and that VR helps students understand interactions among living things (F4, 4.00). Teachers were less certain that VR helps students understand the relationship between biotic and abiotic components (F3, 2.83); this suggests that this concept needs explicit design attention rather than being assumed to be solved by VR. In contrast, teachers' experience with VR was limited: they rated "I have used VR devices or applications" (E3) at 1.83, "I have used VR in learning" (E4) at 1.50, and their understanding of how VR works (E2) at 2.17, yet their interest in using VR for IPAS and their willingness to learn it (E5 and E6) both reached 4.00. All ten feature statements were rated high or very high (G1–G10; 3.17–4.00). Teachers gave 4.00 to an attractive display suited to elementary students, explorable ecosystem environments, narration, simple Indonesian, and usage guides for teachers and students (G1, G2, G5, G8, and G10), while quizzes (G7, 3.33) and compatibility with available devices (G9, 3.17) received the lowest ratings.

The open-ended answers described the conditions under which VR would be accepted. Teachers reported that students find it hard to picture the relationship between biotic and abiotic components and the interactions among living things, and that the media they currently use, namely textbooks, pictures, posters, and video, sometimes with observation of the school yard, are easy to prepare but do not show interactions fully or allow close observation. pictures, posters, and video, sometimes with observation of the school yard, are easy to prepare but do not show interactions fully or allow close observation. They saw VR as an alternative or a complement, provided that it is easy to use. The barriers they expected were the availability and number of devices, cost, preparation time, student supervision, and the comfort and duration of use. Their suggestions included usage guides, a small-group trial first, short age-appropriate content, a version that can be shown on a classroom screen when devices are limited, clear learning objectives, and testing the ease of use before wider application.

Discussion and Design Implications

The pretest–posttest results show that students' critical scientific thinking scores increased after VR-based learning, with a moderate N-gain, and that the pretest mean was already fairly high (75.3), which also limits the room for gain. The increase is consistent with reports that VR media improve elementary students' learning outcomes (Erviana & Sepriansyah, 2024) and with meta-analytic evidence of a positive, moderate effect of educational virtual environments on K-12 science learning (Chen et al., 2026). It can be explained through the cognitive theory of multimedia learning, which holds that well-designed visual and verbal information supports processing in working memory (Mayer, 2024), and through the immersion principle, which suggests that immersion aligned with instructional design can improve learning outcomes (Makransky & Mayer, 2022). The needs analysis helps interpret this result: before VR was used, 60.9% of students often had difficulty imagining the relationship between living things and their environment, which matches earlier reports that

ecosystem concepts are hard to grasp when presented only verbally or in static form (Kuroru & Rahmah, 2023), and VR allowed these relationships, such as the effects of tree cutting or river pollution, to be observed. Because of the one-group design, these explanations remain plausible interpretations and not proof of a VR effect.

Students' strong interest in VR (84.4%) and their view that VR makes learning more enjoyable (87.5%) are in line with studies reporting that virtual environments increase the motivation and self-efficacy of elementary students (Cho et al., 2022) and that VR-based learning in Indonesian elementary schools has the potential to improve learning effectiveness (Herwin et al., 2022). Meta-analytic evidence also supports a positive, moderate effect of educational virtual environments on K-12 science learning (Chen et al., 2026). However, because only 9.4% of students had used a VR device and a quarter were not yet sure about using it, much of this interest reflects expectation rather than experience. High immersion without appropriate instructional design can increase presence without increasing learning (Makransky et al., 2019), so the media must be designed with multimedia learning and cognitive load principles in mind (Mayer, 2024; Zou et al., 2025), and students will need an orientation to the device and guided questions from the teacher (Petersen et al., 2020).

Teachers' views complement those of students. The need for VR media and the requested features were rated very high, yet teachers' knowledge and experience of VR received the lowest ratings across all sections, with device availability, cost, and preparation time identified as barriers. This combination of high demand and limited readiness suggests that VR media should be affordable, easy to operate, and accompanied by practical guidance for teachers and students (Herwin et al., 2022). Teachers also suggested a version that could be displayed on a classroom screen as an alternative when headsets are unavailable. Taken together, the three data sources inform the design of VR media for the next stages of the development model. The content should feature rice paddy and forest ecosystems, clearly illustrating biotic and abiotic components and their relationships, as these were among the most difficult concepts for students and the most requested virtual experiences. Learning activities should include observing plants and animals, identifying ecosystem components, and completing a short interactive quiz, reflecting the needs expressed by both students and teachers.

The media should also provide simple narration in Indonesian and user guides for teachers and students, a feature rated 4.00 by teachers. For delivery, a low-cost 360-degree format using a simple headset should be developed alongside a classroom-screen alternative, with short sessions to manage cognitive load and address teachers' concerns about comfort and duration of use (Makransky et al., 2019). Finally, future research should employ a controlled experimental design with a comparison group and statistically equated parallel-form tests to evaluate the effect of the media on students' critical scientific thinking.

CONCLUSIONS AND RECOMMENDATIONS

This study identified the needs for Virtual Reality media in ecosystem learning in the IPAS subject at the elementary school level and described students' critical scientific thinking before and after VR-based learning. Before VR was used, most students had difficulty imagining the relationships between living things and their environment and wanted more interesting media; students showed high interest in VR (84.4%) despite limited experience (9.4% had used it), and teachers rated the need for VR media (3.67) and the required VR features (3.80) as very high while reporting limited knowledge and experience of VR (2.75). After VR-based learning, the mean score increased from 75.3 to 87.3 (N-gain = 0.49, moderate category; $p < 0.001$), and 59 of the 64 students improved. These findings address the problem raised in the introduction by showing that VR media are needed and are associated with improved critical scientific thinking, provided that the media are simple, affordable, and accompanied by teacher guidance. Because of the one-group design, the improvement cannot be attributed to VR alone.

Prospects for further development include a controlled experimental study with a control group to test the effect of VR on critical scientific thinking, using test forms that are statistically equated. Further research is also recommended to expand the application of VR media to other abstract IPAS topics, such as life cycles, the water cycle, and the solar system, to test on larger and more

demographically diverse samples, to examine the long-term effectiveness of VR through longitudinal studies, to explore the combination of VR with augmented reality (hybrid reality), and to evaluate the cost-affordability and teacher readiness required to sustainably implement VR media in elementary schools. These findings can serve as an initial reference for developing VR media design guidelines for immersive, contextual, and student-centered IPAS learning.

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