

Development of Problem-Based Learning Tools Using Virtual Reality Videos to Enhance Students' Critical Thinking Skills and Climate Change Awareness

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Article Info	Abstract
Article History Received: April 2026; Revised: May 2026; Published: June 2026 Keywords Problem-based learning; Virtual reality videos; Critical thinking; Climate change awareness; Learning tools	Climate change education requires instructional approaches that connect scientific understanding with critical reasoning and environmental awareness. This study developed and evaluated a problem-based learning (PBL) package integrating pre-existing virtual reality videos for Grade X climate change instruction. The package comprised a teaching module, student worksheet, instructional materials, a critical-thinking test, and a climate change awareness questionnaire. Using a Research and Development approach, the package was evaluated for validity, practicality, and effectiveness. Four validators assessed content and construct validity, while two observers evaluated classroom implementation and student activity. Forty students participated in the classroom trial, with 20 assigned to the experimental group and 20 to the control group. Critical thinking was measured before and after instruction in both groups, whereas climate change awareness was assessed only in the experimental group. The learning tools achieved overall content and construct validity means of 3.528 and 3.568, respectively, and classroom implementation and student activity were rated good, with overall means of 3.700 and 3.800. Critical-thinking scores in the experimental group increased from 1.608 to 3.725, compared with 1.583 to 1.808 in the control group. A significant Group $\times$ Time interaction was found, $F(1, 38) = 780.120$, $p < .001$, partial $\eta^2 = .954$. Climate change awareness increased from 2.070 to 3.925, with a moderate normalized gain of 0.632 and a significant time effect, $F(1, 19) = 2698.843$, $p < .001$, partial $\eta^2 = .993$. The findings support the pedagogical potential of integrating existing virtual reality videos within a structured PBL learning package for schools.  https://doi.org/10.36312/crr6z869 Copyright© 2026, Rizal & de Jesus This is an open-access article under the CC-BY-SA License 
How to Cite	Rizal, S., & de Jesus, M. M. . (2026). Development of Problem-Based Learning Tools Using Virtual Reality Videos to Enhance Students' Critical Thinking Skills and Climate Change Awareness. <i>International Journal of Essential Competencies in Education</i> , 5(1), 74-95. https://doi.org/10.36312/crr6z869

INTRODUCTION

Climate change has become an increasingly important educational concern because its consequences extend beyond scientific understanding to social, economic, and environmental decision-making. Learning about climate change therefore requires students not only to understand scientific concepts but also to interpret evidence, consider the consequences of environmental change, evaluate mitigation and adaptation options, and develop a sense of responsibility toward environmental problems (Bleazby et al., 2023; Eilam, 2022). These demands make climate change particularly relevant to the development of higher-order

thinking because students must connect scientific knowledge with complex real-world situations in which evidence, consequences, and possible actions need to be critically examined. Critical-thinking activities have been shown to support students' comprehension of climate change and their capacity to make evidence-based judgments (Young et al., 2023). In the Indonesian context, climate change is included in Phase E of the Merdeka Curriculum for Grade X, providing an important curricular opportunity to connect scientific understanding with reasoning about environmental problems. Climate change education at this level should therefore move beyond the transmission of factual knowledge and provide learning experiences that encourage students to examine causes, interpret evidence, evaluate alternatives, formulate explanations, and reflect on possible actions.

Despite these educational demands, conventional classroom instruction does not always provide sufficient opportunities for students to engage in the reasoning processes required for meaningful climate change learning. Teacher-centered approaches may emphasize the delivery and reproduction of information while providing limited opportunities for students to interrogate evidence, construct explanations, examine competing alternatives, or justify decisions. Previous studies have identified gaps between the intended goals of climate change curricula and the depth of knowledge and engagement demonstrated during classroom implementation (Eilam et al., 2020). Low levels of critical thinking and environmental-care attitudes have also been reported among students studying global warming and climate change, indicating that conceptual exposure alone may be insufficient to develop the reasoning and dispositions required to respond to environmental problems (Hillary et al., 2023). Interactive climate change materials have consequently been proposed as one means of strengthening students' critical thinking and scientific attitudes (Pursitasari et al., 2023). These findings suggest that the central instructional challenge is not simply to provide students with more information about climate change, but to organize learning so that students actively investigate environmental problems, evaluate information, discuss possible explanations, and consider scientifically informed actions.

Problem-based learning (PBL) provides a relevant pedagogical structure for addressing this challenge because it positions complex and authentic problems as the starting point for learning. Within PBL, students are expected to organize existing knowledge, identify what they need to investigate, examine evidence, collaborate with peers, propose solutions, justify decisions, and reflect on the outcomes of their inquiry. These characteristics are consistent with established principles of PBL in STEM education, particularly the use of authentic problems, student responsibility, facilitation, collaboration, and reflective learning (Smith et al., 2022). They are also closely related to the cognitive processes involved in critical thinking. Interpretation requires students to identify the meaning of information presented in a problem; analysis requires examination of relationships among causes, evidence, and consequences; evaluation involves judging the credibility and relevance of evidence and proposed solutions; inference requires drawing reasonable conclusions; explanation involves articulating and defending conclusions; and self-regulation requires reflection on reasoning and proposed actions (Facione, 2020). In climate change education, PBL can therefore provide a pedagogical mechanism through which scientific knowledge is connected with authentic environmental problems while students repeatedly practice the reasoning processes targeted in critical-thinking assessment. Its potential value lies not simply in engaging students in activities, but in structuring those activities around evidence, problem investigation, collaborative reasoning, decision-making, and reflection.

Digital visualization can further support this pedagogical structure because many climate-related processes operate across spatial and temporal scales that are difficult for

students to observe directly in conventional classrooms. Digital learning environments can expand access to information and representations of complex phenomena, but access to technology does not automatically produce deep learning or critical reasoning (Newsome et al., 2023; Sollied-Madsen et al., 2021). Students may remain passive recipients of digital information if the media are not embedded within tasks that require inquiry, interpretation, analysis, and reflection. Learning environments that encourage active exploration are therefore particularly relevant when students study environmental change that cannot easily be experienced directly (Chusni et al., 2021). Virtual reality videos offer one form of visual representation that can make climate-related situations more immediate and contextually meaningful. Virtual climate experiences have been associated with changes in climate-related cognition and emotion, suggesting that immersive representations can increase the salience of environmental phenomena that might otherwise appear distant or abstract (Meijers et al., 2023). However, the educational value of such representations depends on their pedagogical use. A virtual reality video viewed in isolation may provide visual exposure, whereas the same video embedded within structured problem investigation can function as evidence or contextual stimulus for analysis, discussion, decision-making, and reflection.

Previous research provides support for combining problem-oriented learning with digital representations in climate change education, but it also indicates an unresolved instructional-development problem. Climate change virtual reality video has previously been incorporated into problem-based remote learning to support critical-thinking development, demonstrating that immersive video can be used meaningfully within a problem-solving sequence (Aliyu et al., 2023). More broadly, effective climate change education has been associated with personally meaningful information, active engagement, deliberation, and opportunities for learners to consider solutions to environmental problems (Monroe et al., 2019). Studies of digital and blended learning also indicate that technology is most educationally useful when it is subordinated to a coherent instructional design rather than treated as an instructional objective in itself (Herodotou et al., 2020; Palvia et al., 2018). A digital pedagogical model integrating climate change issues with virtual reality has also been proposed to enhance critical thinking and climate change awareness through problem orientation, knowledge organization, exploration, presentation, and reflection (Suryati et al., 2025). However, a pedagogical model does not by itself provide teachers with a complete classroom-ready system. Classroom implementation requires operational teaching modules, student worksheets, instructional materials, assessment instruments, structured activity sequences, and guidance for integrating media into the learning process. The importance of systematically structured digital learning materials has similarly been recognized in the development of climate change resources designed to strengthen students' digital literacy (Mufidah et al., 2023).

The unresolved issue, therefore, is not whether PBL or virtual reality can be used in climate change education independently, nor whether they can simply be combined. Rather, there remains a need to examine how an existing PBL–virtual reality pedagogical concept can be translated into a coherent, validated, and classroom-ready learning package and how that package performs when implemented with secondary-school students. Such evaluation requires evidence that the learning tools are conceptually appropriate and internally consistent, that their instructional phases can be implemented practically in classroom conditions, and that implementation is accompanied by meaningful learning outcomes. This distinction is important because the present study does not develop virtual reality technology or produce new virtual reality content. Instead, it uses pre-existing third-party virtual reality videos as instructional media within a structured PBL system. The video functions as a

contextual stimulus for investigating climate change and carbon-footprint problems, while the learning sequence requires students to organize knowledge, explore causes and consequences, evaluate mitigation alternatives, present conclusions, and reflect on possible actions. The scientific contribution must therefore be assessed at the level of the complete instructional package rather than attributed to the virtual reality video as an isolated technological intervention.

Novelty of the Current Study

The novelty of the current study lies in the systematic pedagogical operationalization of pre-existing virtual reality videos within a complete PBL learning package, rather than in the development of virtual reality technology or in the simple combination of PBL and virtual reality. Previous work has demonstrated the potential of climate-related virtual reality experiences and has proposed problem-based and digitally supported approaches for climate change learning (Aliyu et al., 2023; Meijers et al., 2023; Suryati et al., 2025). The present study extends this line of work by translating the pedagogical principles into a classroom-ready system comprising a teaching module, student worksheet, instructional materials, critical-thinking assessment, and climate change awareness questionnaire.

A second element of novelty concerns the organization of virtual reality media within an explicit instructional sequence. Rather than using virtual reality video as a stand-alone learning resource, the video is embedded within phases of problem orientation, knowledge organization, deep exploration, presentation, and discussion and reflection. This arrangement places technology in a supporting role within a broader process of collaborative inquiry and evidence-based problem solving. A third contribution is the multi-criterion evaluation of the resulting package. The study examines content and construct validity, classroom implementation and student activity as indicators of practicality, experimental-control differences in critical-thinking performance, and pretest-posttest changes in climate change awareness. The contribution therefore concerns the development and empirical evaluation of an integrated instructional system rather than the independent effect of virtual reality technology.

Research Objectives and Questions

Accordingly, this study aimed to develop and evaluate a PBL learning package integrating pre-existing virtual reality videos for Grade X climate change instruction. Specifically, the study examined the content and construct validity of the developed learning tools, evaluated their practicality through classroom implementation and student activity, investigated changes in critical-thinking performance using experimental and control groups, and assessed changes in climate change awareness among students who participated in the intervention. Because climate change awareness data were available only for the experimental group, the study evaluates pretest-posttest change in awareness rather than a between-group treatment effect.

The study addressed the following research questions:

- (1) To what extent are the developed PBL learning tools integrating virtual reality videos valid in terms of content and construct validity?
- (2) To what extent can the developed learning tools be practically implemented in Grade X climate change instruction, as reflected in learning implementation and student activity?
- (3) Do students who learn through the developed PBL learning package using virtual reality videos demonstrate greater improvement in critical-thinking skills than students receiving conventional expository instruction?

- (4) How does students' climate change awareness change following participation in the PBL learning intervention using virtual reality videos?

METHODS

Research Design and Development Procedure

This study employed a Research and Development approach to develop and evaluate a problem-based learning (PBL) learning package integrating virtual reality videos for climate change instruction. The development procedure was informed by educational design research principles emphasizing systematic design, formative evaluation, and product-quality assessment, together with established educational research and development procedures (Akker et al., 2013; Gall et al., 2007; Nieveen et al., 2023). The developed package was evaluated across three quality dimensions: validity, practicality, and effectiveness. Validity concerned the appropriateness and internal consistency of the learning tools, practicality concerned their implementation under classroom conditions, and effectiveness concerned changes in students' critical thinking and climate change awareness following implementation.

The development process began with a preliminary investigation involving a literature review, classroom observation, identification of instructional problems, analysis of learner needs, and formulation of climate change learning objectives. These activities informed the development of Draft I, an integrated learning package comprising a teaching module, student worksheet, climate change instructional materials, a critical-thinking test, and a climate change awareness questionnaire. Draft I was independently evaluated by experts and practitioners, and the resulting judgments and recommendations were used to revise the package and produce Draft II. The revised package was subsequently implemented in the classroom. The development procedure allowed for a second implementation in another school if the first implementation did not meet the predetermined criteria for practicality and effectiveness. As the initial implementation satisfied these criteria, no second implementation was conducted.

The study did not develop virtual reality technology or produce new virtual reality video content. A pre-existing third-party virtual reality video was instead incorporated as an instructional resource within the PBL sequence. Accordingly, the product evaluated in this study was the complete PBL learning package and the pedagogical organization of its components rather than the virtual reality technology itself.

Participants, Setting, and Experimental Design

Participants were Grade X senior-secondary students in Phase E of the Indonesian Merdeka Curriculum who had not previously received instruction on the climate change topic addressed in the study. Participants were selected purposively according to these criteria. Classroom implementation involved 40 students at School A, with 20 students in the experimental group and 20 students in the control group. The experimental group received instruction using the developed PBL learning package integrating virtual reality videos, whereas the control group received conventional expository instruction based primarily on teacher explanation and question-and-answer activities.

The study was conducted during the 2024/2025 academic year over four meetings. The first meeting was allocated to pretesting, the second and third meetings to instruction, and the fourth meeting to posttesting. Each instructional meeting consisted of two 45-minute periods. The researcher served as the instructor during implementation, while two independent observers assessed the enactment of the planned instructional phases and corresponding student activities.

The outcome-measurement structure differed between critical thinking and climate change awareness. Critical thinking was assessed at pretest and posttest in both the experimental and control groups, whereas climate change awareness was assessed at both measurement occasions only in the experimental group. Table 1 summarizes the study design and outcome measurements.

Table 1. Experimental design and outcome measurements

Group	N	Pretest	Instruction	Posttest
Experimental	20	Critical thinking; climate change awareness	PBL learning package integrating virtual reality videos	Critical thinking; climate change awareness
Control	20	Critical thinking	Conventional expository instruction	Critical thinking

The critical-thinking measurement structure permitted examination of differences in change over time between the two instructional groups. Climate change awareness followed a within-group pretest-posttest structure; consequently, this outcome was evaluated as change over time within the experimental group rather than as a direct experimental-control effect.

Learning Tools and Instructional Intervention

The developed learning package consisted of five mutually supporting learning tools: a teaching module, student worksheet, climate change instructional materials, a critical-thinking test, and a climate change awareness questionnaire. The instructional sequence followed five phases adapted from a digital pedagogical model for climate change learning: orientation to climate change issues or problems, organization of climate change knowledge structures, deep exploration of climate change problem solving, presentation of problem-exploration results, and discussion and reflection on climate change issues (Suryati et al., 2025).

During the orientation phase, students were introduced to climate-related issues that established the context for subsequent investigation. The knowledge-organization phase focused on structuring relevant information and concepts before deeper exploration. During the deep-exploration phase, students worked collaboratively in groups of three to four and examined climate-related problems represented through a pre-existing virtual reality video. The accompanying worksheet guided students to investigate the relationship between climate change and carbon footprints, identify causes and consequences, evaluate mitigation strategies, propose actions for reducing global warming, discuss their findings, and formulate group conclusions.

The relationship among the instructional materials, student worksheet, and virtual reality video is illustrated in Figure 1. The figure presents representative components of the learning package and shows how the third-party virtual reality video was embedded within the PBL learning sequence rather than used as a stand-alone technological intervention.

Figure 1 illustrates the pedagogical organization of the main intervention components. The climate change instructional material provided the conceptual foundation, while the carbon-footprint worksheet connected the virtual reality video with structured problem investigation. Students were required to examine causes and consequences, analyze the relationship between carbon footprints and climate change, evaluate mitigation strategies, propose actions, discuss alternative solutions, and formulate conclusions.

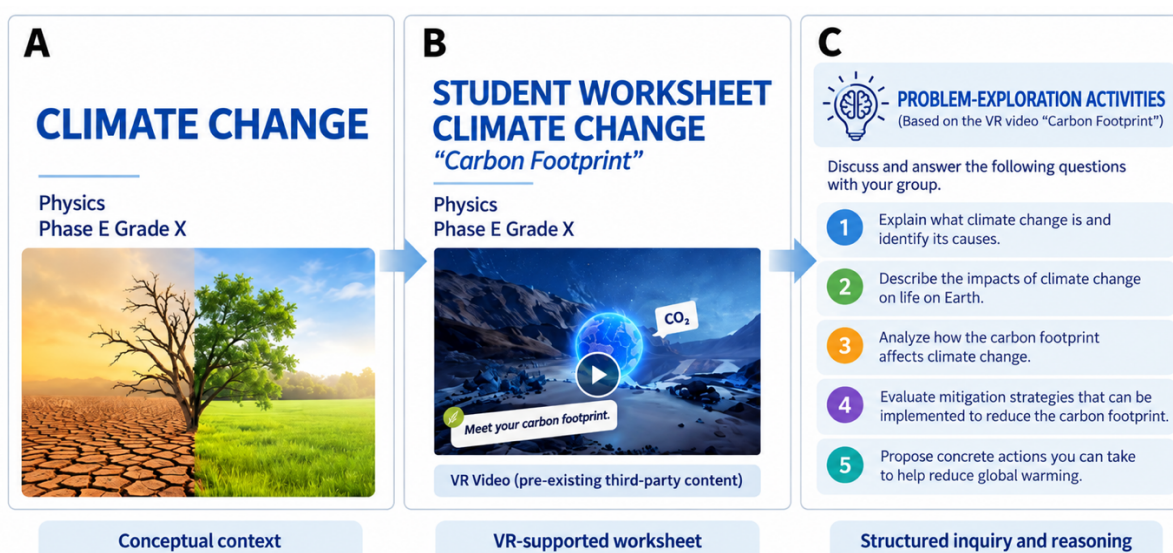


Figure 1. Representative components of the developed PBL learning package: (A) climate-change instructional material providing the conceptual context, (B) the carbon-footprint student worksheet incorporating a pre-existing third-party virtual reality video, and (C) structured problem-exploration activities supporting inquiry and reasoning.

The virtual reality video therefore functioned as a contextual and visual resource within a broader inquiry sequence. Its use was integrated with collaborative problem solving, structured reasoning, presentation, and reflection, allowing the learning package to operationalize the PBL process around an authentic environmental issue.

Validation, Research Instruments, and Data Collection

Four validators with relevant expertise and practical experience independently evaluated the developed learning tools. Content validity and construct validity were rated using a five-point scale ranging from 1, representing not valid, to 5, representing highly valid. Content validity addressed the extent to which the learning tools reflected instructional needs and current knowledge, whereas construct validity addressed the logical organization and consistency among their components (Akker et al., 2013).

Practicality was assessed by two independent observers using classroom-implementation and student-activity observation sheets. Both instruments employed five-point rating scales. Classroom implementation represented the extent to which the planned PBL phases were enacted as designed, whereas student activity represented participation in the corresponding instructional activities. Inter-observer consistency was evaluated using percentage agreement, with agreement of at least 75% considered acceptable (Borich, 2016).

Critical thinking was measured using six essay items representing interpretation, analysis, evaluation, inference, explanation, and self-regulation. Each item was scored from 0 to 4, with higher scores indicating increasingly accurate responses supported by appropriate concepts, evidence, and reasoning (Ekayanti et al., 2022). An overall critical-thinking score was obtained for each student by averaging the scores across the six items.

Climate change awareness was measured using a 20-item five-point Likert-type questionnaire ranging from 1 (strongly disagree) to 5 (strongly agree). The questionnaire represented seven dimensions: understanding of climate change, awareness of climate impacts, attitudes toward climate change, everyday environmental actions, participation in environmental activities, knowledge of climate change mitigation, and perceptions of the role

of education (Suryati et al., 2025). Item responses were averaged to obtain each student's overall awareness score.

The constructs, research instruments, measured components, and scoring scales are summarized in Table 2.

Table 2. Research instruments and data sources

Construct	Instrument	Main indicators/components	Scale
Content and construct validity	Expert-validation sheets	Teaching module, student worksheet, instructional materials, critical-thinking test, awareness questionnaire	1–5
Learning implementation	Observation sheet	Five PBL phases	1–5
Student learning activity	Observation sheet	Participation in each PBL phase	1–5
Critical thinking	Six-item essay test	Interpretation, analysis, evaluation, inference, explanation, self-regulation	0–4
Climate change awareness	20-item Likert-type questionnaire	Seven awareness dimensions	1–5

The validation instruments were administered before classroom implementation. Classroom-implementation and student-activity observations were conducted during the two instructional meetings. Critical-thinking assessments were administered to both groups before and after instruction, whereas the climate change awareness questionnaire was administered at the same measurement occasions only to the experimental group.

Data Analysis

Content-validity and construct-validity data were summarized using the mean, standard error, and standard deviation. Classroom implementation and student activity were summarized using phase-level and overall mean scores, while consistency between the two observers was assessed using percentage agreement. The five-level interpretation framework used for validity, classroom implementation, student activity, and climate change awareness is presented in Table 3.

Table 3. Interpretation criteria for developmental evaluation and climate change awareness

Mean score	Validity	Implementation/activity	Awareness
> 4.21	Highly valid	Very good	Very high
> 3.40–4.21	Valid	Good	High
> 2.60–3.40	Moderately valid	Moderate	Moderate
> 1.79–2.60	Less valid	Poor	Low
≤ 1.79	Not valid	Very poor	Very low

Critical-thinking scores above 3.21 were categorized as highly critical, scores above 2.40 to 3.21 as critical, scores above 1.60 to 2.40 as moderately critical, scores above 0.80 to 1.60 as less critical, and scores of 0.80 or below as not critical (Ekayanti et al., 2022). Pretest-posttest improvement was also expressed using normalized gain. Individual normalized gains were calculated for each student relative to the maximum critical-thinking or awareness score and were subsequently averaged within the relevant group. Mean normalized gains above 0.70 were classified as high, values from 0.30 to 0.70 as moderate, and values below 0.30 as low (Hake, 1999).

Individual score distributions were additionally visualized using raincloud plots combining raw observations, boxplot summaries, and density distributions. These plots were used to complement the descriptive statistics by displaying the distribution and overlap of scores across measurement occasions and instructional groups.

Critical-thinking outcomes were analyzed using a 2×2 mixed analysis of variance (ANOVA). Instructional group (experimental vs. control) served as the between-subject factor, and measurement time (pretest vs. posttest) served as the within-subject factor. The Group $\times$ Time interaction constituted the primary inferential test for determining whether the magnitude of critical-thinking change differed between the experimental and control groups. The main effects of group and time were also reported. Effect sizes for the mixed ANOVA were expressed as partial eta squared.

Planned follow-up one-way ANOVAs compared experimental and control critical-thinking scores separately at pretest and posttest. The pretest analysis examined initial group comparability, whereas the posttest analysis characterized the between-group difference following instruction. Eta squared was reported as the effect-size measure for these between-group comparisons.

Climate change awareness was analyzed using a one-factor repeated-measures ANOVA with measurement time (pretest vs. posttest) as the within-subject factor. This analysis evaluated change in awareness within the experimental group. Partial eta squared was reported as the corresponding effect-size measure. No between-group analysis of climate change awareness was conducted because corresponding awareness measurements were not available for the control group. The inferential analysis plan is summarized in Table 4.

Table 4. Inferential statistical analyses

Outcome	Comparison/effect	Statistical analysis	Effect size	Analytical purpose
Critical thinking	Group, Time, and Group $\times$ Time	2×2 mixed ANOVA	Partial η^2	Test whether change over time differed between groups
Critical thinking	Experimental vs. control at pretest	One-way ANOVA	η^2	Examine initial group comparability
Critical thinking	Experimental vs. control at posttest	One-way ANOVA	η^2	Examine the post-instruction between-group difference
Climate change awareness	Experimental pretest vs. posttest	Repeated-measures ANOVA	Partial η^2	Examine within-group change over time

All inferential tests used a significance threshold of $p < .05$. Distributional assumptions were examined using the Shapiro–Wilk test, and homogeneity of variance for between-group comparisons was assessed using Levene’s test. As the within-subject factor contained only two measurement occasions, the sphericity assumption did not require separate testing. The balanced group sizes and variance diagnostics were considered when interpreting the mixed-ANOVA results.

RESULTS AND DISCUSSION

Validity of the Developed Learning Tools

The validity of the developed learning tools was examined in terms of content validity and construct validity. Four validators independently evaluated the five components of the

PBL learning package: the teaching module, student worksheet, instructional materials, critical-thinking test, and climate change awareness questionnaire. The aggregate validation results are presented in Table 5.

Table 5. Content and construct validity of the developed learning tools

Learning tool	Validation aspect	Mean	SE	SD	Category
Teaching module	Content validity	3.550	0.094	0.209	Valid
	Construct validity	3.500	0.158	0.354	Valid
Student worksheet	Content validity	3.583	0.105	0.258	Valid
	Construct validity	3.679	0.105	0.278	Valid
Instructional materials	Content validity	3.571	0.130	0.345	Valid
	Construct validity	3.571	0.105	0.278	Valid
Critical-thinking test	Content validity	3.563	0.063	0.125	Valid
	Construct validity	3.542	0.150	0.368	Valid
Climate change awareness questionnaire	Content validity	3.375	0.217	0.433	Moderately valid
	Construct validity	3.550	0.200	0.447	Valid
Overall	Content validity	3.528	0.122	0.274	Valid
	Construct validity	3.568	0.144	0.345	Valid

As shown in Table 5, the overall mean scores for content validity and construct validity were 3.528 and 3.568, respectively, placing both dimensions in the valid category. The student worksheet obtained the highest construct-validity score ($M = 3.679$), while the teaching module, instructional materials, and critical-thinking test also met the predetermined criteria for both content and construct validity.

The climate change awareness questionnaire was the only component with a content-validity score in the moderately valid category ($M = 3.375$), whereas its construct-validity score ($M = 3.550$) met the valid criterion. Overall, the validation results indicate that the developed learning tools satisfied the required content- and construct-validity criteria, although the awareness questionnaire showed comparatively lower content validity than the other components.

Practicality of Classroom Implementation

The practicality of the developed learning package was examined through two dimensions: implementation of the planned instructional phases and student participation in the corresponding learning activities. The first three PBL phases were conducted during the first instructional meeting, whereas the presentation and discussion-reflection phases were conducted during the second instructional meeting. Two observers independently assessed both dimensions. The results are summarized in Table 6.

Table 6. Classroom implementation and student activity across the PBL phases

PBL phase	Meeting	Implementation mean	Student-activity mean
Orientation to climate change issues/problems	1	3.500	4.000
Organization of climate change knowledge structures	1	4.000	3.500
Deep exploration of climate change problem solving	1	4.000	3.500

PBL phase	Meeting	Implementation mean	Student-activity mean
Presentation of problem-exploration results	2	3.500	4.000
Discussion and reflection on climate change issues	2	3.500	4.000
Overall mean		3.700	3.800

Table 6 shows that all five PBL phases were implemented within the good category. Knowledge organization and deep exploration obtained the highest implementation means, both at 4.000, whereas orientation, presentation, and discussion-reflection each achieved a mean of 3.500. The overall implementation mean was 3.700.

Student activity was rated in the good category across all five phases. Orientation, presentation, and discussion-reflection each obtained mean activity scores of 4.000, whereas knowledge organization and deep exploration each obtained a mean score of 3.500. The overall student-activity mean was 3.800. Agreement between the two observers reached 91.43% for instructional implementation and 94.29% for student activity, exceeding the predetermined 75% criterion for acceptable agreement. Taken together, these results indicate that the developed PBL learning package was practically implementable in the classroom context.

Critical-Thinking Outcomes

Critical thinking was assessed across six indicators: interpretation, analysis, evaluation, inference, explanation, and self-regulation. Table 7 presents the pretest and posttest descriptive statistics for the experimental and control groups.

Table 7. Critical-thinking scores by indicator and instructional group

Critical-thinking indicator	Experimental		Control	
	Pretest M $\pm$ SD	Posttest M $\pm$ SD	Pretest M $\pm$ SD	Posttest M $\pm$ SD
Interpretation	1.650 $\pm$ 0.489	3.850 $\pm$ 0.366	1.850 $\pm$ 0.366	1.850 $\pm$ 0.366
Analysis	1.450 $\pm$ 0.510	3.650 $\pm$ 0.489	1.600 $\pm$ 0.503	1.950 $\pm$ 0.224
Evaluation	1.950 $\pm$ 0.224	3.600 $\pm$ 0.503	1.750 $\pm$ 0.444	1.900 $\pm$ 0.308
Inference	1.850 $\pm$ 0.366	3.650 $\pm$ 0.489	1.800 $\pm$ 0.410	1.800 $\pm$ 0.410
Explanation	1.500 $\pm$ 0.513	3.750 $\pm$ 0.444	1.350 $\pm$ 0.489	1.700 $\pm$ 0.470
Self-regulation	1.250 $\pm$ 0.444	3.850 $\pm$ 0.366	1.150 $\pm$ 0.366	1.650 $\pm$ 0.489
Overall	1.608 $\pm$ 0.156	3.725 $\pm$ 0.135	1.583 $\pm$ 0.199	1.808 $\pm$ 0.165

The experimental group showed increases across all six critical-thinking indicators. Its overall mean increased from 1.608 at pretest, corresponding to the moderately critical category, to 3.725 at posttest, corresponding to the highly critical category. The largest absolute increase was observed for self-regulation, which increased from 1.250 to 3.850, followed by explanation, which increased from 1.500 to 3.750. Interpretation, analysis, evaluation, and inference also reached the highly critical category at posttest.

In comparison, changes in the control group were smaller. Its overall mean increased from 1.583 at pretest to 1.808 at posttest. Interpretation remained unchanged at 1.850, and inference remained unchanged at 1.800, while analysis, evaluation, explanation, and self-regulation showed relatively modest increases. The mean pretest-posttest change was 2.117 points in the experimental group and 0.225 points in the control group. The corresponding

normalized gains were 0.884 for the experimental group and 0.089 for the control group, representing high and low gains, respectively.

The distributions of individual critical-thinking scores across measurement occasions are presented in Figure 2.

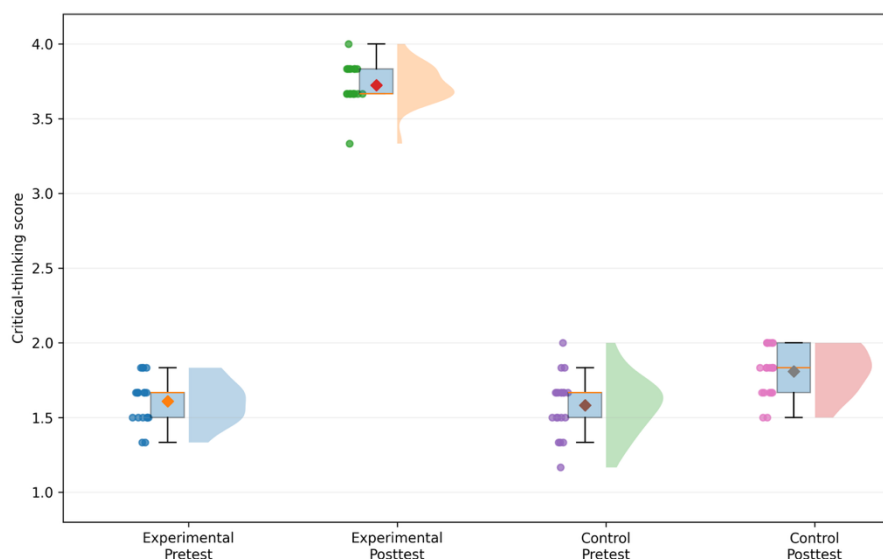


Figure 2. Raincloud plot of pretest and posttest critical-thinking scores in the experimental and control groups.

Figure 2 displays individual observations together with boxplot summaries and density distributions for each measurement condition. The experimental-group distribution shifted markedly upward from pretest to posttest, with limited overlap between the two distributions. Experimental-group posttest scores were concentrated toward the upper end of the scale, consistent with the higher posttest mean reported in Table 7.

In contrast, the control-group pretest and posttest distributions showed substantial overlap. Although some students obtained slightly higher posttest scores, the distributional shift was considerably smaller than that observed in the experimental group. A 2×2 mixed ANOVA was subsequently used to test differences in change over time, with instructional group as the between-subject factor and measurement time as the within-subject factor. The results are presented in Table 8.

Table 8. Mixed ANOVA for critical-thinking scores

Effect	df1	df2	F	p	Partial η^2
Group	1	38	595.893	< .001	.940
Time	1	38	1195.425	< .001	.969
Group $\times$ Time	1	38	780.120	< .001	.954

The mixed ANOVA revealed a significant main effect of time, $F(1, 38) = 1195.425$, $p < .001$, partial $\eta^2 = .969$, indicating an overall difference between pretest and posttest scores. A significant main effect of group was also observed, $F(1, 38) = 595.893$, $p < .001$, partial $\eta^2 = .940$.

The Group $\times$ Time interaction was also significant, $F(1, 38) = 780.120$, $p < .001$, partial $\eta^2 = .954$. The significant interaction indicates that the magnitude of pretest-posttest change differed between the experimental and control groups. The interaction was associated with a partial η^2 of .954, consistent with the marked difference in score changes observed between the two groups.

To further characterize the between-group differences at each measurement occasion, separate one-way ANOVAs were conducted for the pretest and posttest scores. The results are presented in Table 9.

Table 9. Between-group ANOVA for critical-thinking scores

Measurement	F(1, 38)	p	η^2
Pretest	0.196	.660	.005
Posttest	1615.916	< .001	.977

As shown in Table 9, no significant difference was observed between the experimental and control groups at pretest, $F(1, 38) = 0.196$, $p = .660$, $\eta^2 = .005$, indicating comparable initial critical-thinking scores. In contrast, a significant between-group difference was observed at posttest, $F(1, 38) = 1615.916$, $p < .001$, $\eta^2 = .977$.

Taken together, the indicator-level scores, normalized gains, raincloud distributions, and Group $\times$ Time interaction consistently indicate greater improvement in critical thinking in the experimental group than in the control group.

Climate Change Awareness Outcomes

Climate change awareness was assessed at pretest and posttest in the experimental group. The descriptive results are presented in Table 10.

Table 10. Climate change awareness scores in the experimental group

Measurement	N	Mean	SD	Category	N-gain
Pretest	20	2.070	0.111	Low	0.632
Posttest	20	3.925	0.099	High	

As shown in Table 10, the mean climate change awareness score increased from 2.070 at pretest to 3.925 at posttest, representing a mean increase of 1.855 points. The categorical interpretation therefore shifted from low awareness at pretest to high awareness at posttest. The mean normalized gain was 0.632, corresponding to the moderate-gain category.

At the individual level, all students obtained higher awareness scores at posttest than at pretest. Individual normalized gains ranged from 0.561 to 0.690, indicating that the increase was observed across the entire experimental group. The distributional change is presented in Figure 3.

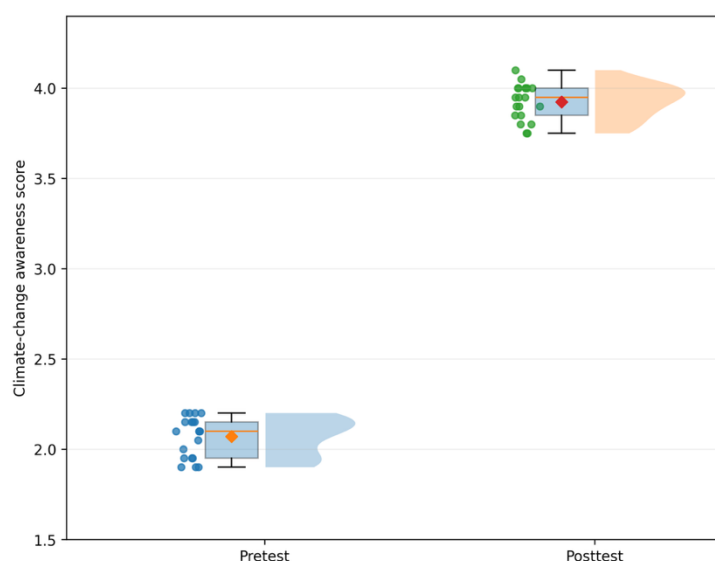


Figure 3. Raincloud plot of pretest and posttest climate change awareness scores in the experimental group.

Figure 3 shows a clear upward shift in the distribution of climate change awareness scores from pretest to posttest. Pretest observations were concentrated around 2.0, whereas posttest observations clustered around 3.9. The limited overlap between the two distributions is consistent with the increase in mean awareness scores shown in Table 10.

A one-factor repeated-measures ANOVA was used to examine the change in climate change awareness across the two measurement occasions. The results are presented in Table 11.

Table 11. Repeated-measures ANOVA for climate change awareness

Effect	df1	df2	F	p	Partial η^2
Time	1	19	2698.843	< .001	.993

The repeated-measures ANOVA revealed a significant effect of time, $F(1, 19) = 2698.843$, $p < .001$, partial $\eta^2 = .993$, indicating that climate change awareness scores were significantly higher at posttest than at pretest.

Climate change awareness was assessed only in the experimental group. Accordingly, the observed change represents a within-group pretest-posttest difference rather than a comparative intervention effect. The results indicate a substantial increase in awareness following participation in the developed PBL learning package, while no corresponding experimental-control comparison is available for this outcome.

Discussion

The findings indicate that the developed PBL learning package integrating virtual reality videos achieved acceptable quality across the major dimensions examined in this study. The learning tools were generally valid in terms of content and construct, the instructional sequence was practically implemented with active student participation, and students in the experimental group demonstrated substantially greater improvement in critical thinking than those receiving conventional expository instruction. Climate change awareness also increased markedly within the experimental group. Taken together, these findings support the feasibility of translating a PBL–virtual reality pedagogical concept into an integrated classroom-ready package rather than treating virtual reality as an isolated technological intervention. This interpretation is consistent with educational design perspectives in which the quality of an instructional product depends on alignment among intended content, instructional organization, implementation, and expected outcomes (Akker et al., 2013; Nieveen et al., 2023).

The validity findings suggest that the individual components of the learning package were sufficiently aligned to support the intended instructional process. The teaching module established the instructional sequence, the student worksheet structured collaborative problem exploration, the instructional materials provided the conceptual basis for understanding climate change, and the assessment instruments represented the targeted critical-thinking and awareness outcomes. Such alignment is important in PBL because authentic problems alone do not necessarily produce productive inquiry. Students also require structured opportunities to organize information, examine evidence, negotiate interpretations, evaluate possible solutions, and communicate conclusions. Previous studies have similarly characterized PBL as an approach that supports authentic problem solving, active inquiry, collaboration, and the development of reasoning in science and STEM contexts (Smith et al., 2022; Tapilouw et al., 2017; Widowati et al., 2021). The validity of the package therefore reflects not merely the adequacy of individual learning tools but also the coherence of their functions within a common instructional system.

The climate change awareness questionnaire warrants more cautious consideration than the other components because its content-validity score remained within the moderately valid category even though its construct validity met the valid criterion. This pattern may partly reflect the breadth of the construct represented by the questionnaire. Climate change awareness in this study encompassed conceptual understanding, awareness of impacts, attitudes, everyday environmental actions, participation in environmental activities, mitigation knowledge, and perceptions of the role of education. Climate-related awareness has similarly been described as extending beyond factual knowledge to include attitudes, participation, and action-oriented dimensions (Akrofi et al., 2019; Álvarez-Nieto et al., 2022; Kousar et al., 2022; Suryati et al., 2025). The comparatively lower content-validity score therefore suggests that further refinement may be required to ensure balanced representation of these dimensions rather than indicating that the overall instructional package lacked validity.

The practicality findings further indicate that the learning package could be enacted as intended under the observed classroom conditions. All five instructional phases—problem orientation, knowledge organization, deep exploration, presentation, and discussion-reflection—were implemented within the good category, while student activity was also rated as good throughout the sequence. This pattern suggests that the structure of the package provided a workable progression from initial engagement with climate-related problems toward increasingly active investigation, communication, and reflection. The five-phase sequence is consistent with the digital pedagogical framework proposed by Suryati et al. (2025), in which problem orientation and knowledge organization prepare students for deeper exploration before presentation and reflective discussion. The observed student participation is also consistent with previous research showing that PBL can provide opportunities for students to investigate authentic problems, collaborate with peers, and refine their reasoning through exploration and discussion (Calkins et al., 2020; Li & Tsai, 2017).

Within this process, the virtual reality video appears to have functioned as a contextual and visual resource rather than as a stand-alone intervention. Climate change involves processes and consequences that may be spatially distant, temporally extended, or difficult to observe directly in conventional classrooms. Digital and immersive representations can make these phenomena more salient and experientially accessible, while previous studies have associated virtual environments with engagement, scientific exploration, and changes in climate-related cognition and emotion (Meijers et al., 2023; Chusni et al., 2021). In the present learning package, however, students did not merely view a virtual reality video. The video was embedded within worksheet-guided problem exploration that required students to examine carbon footprints, identify causes and consequences, evaluate mitigation alternatives, discuss evidence, and formulate conclusions. The educational contribution should therefore be understood as arising from the pedagogical integration of visualization, inquiry, collaboration, and reflection rather than from exposure to virtual reality alone.

The clearest learning-outcome finding concerned critical thinking. Students in the experimental group improved across all six measured dimensions, whereas changes in the control group were comparatively limited. The significant Group $\times$ Time interaction further confirmed that the magnitude of pretest-posttest change differed between the two instructional groups. This pattern is theoretically consistent with the structure of the learning activities. Interpretation was required when students made sense of information presented in climate-related problems; analysis was practiced when examining relationships among human activities, carbon footprints, and environmental consequences; evaluation was involved in judging mitigation alternatives; inference was required when anticipating

consequences and drawing conclusions; explanation was practiced through presentation and justification; and self-regulation was reinforced through discussion and reflection. These processes correspond closely to the dimensions of purposeful and reflective critical thinking proposed by Facione (2020).

The particularly strong increase in self-regulation is pedagogically noteworthy. Self-regulation involves monitoring and, when necessary, revising one's own reasoning, while explanation requires students to articulate and justify the conclusions they reach (Facione, 2020). The experimental learning sequence repeatedly moved students from problem exploration to presentation, peer discussion, and reflection. Such a sequence may have required them not only to generate solutions but also to reconsider the adequacy of those solutions after encountering alternative perspectives. This interpretation is consistent with evidence that exploration and investigation in PBL can support the development of critical reasoning and that problem-oriented learning can strengthen reasoning performance when students are required to construct, communicate, and defend solutions (Anggraeni et al., 2023; Calkins et al., 2020; Li & Tsai, 2017).

The critical-thinking findings are especially relevant to climate change education because this domain requires substantially more than the recall of scientific facts. Students must interpret evidence, analyze relationships among environmental and human systems, evaluate competing mitigation and adaptation strategies, and formulate reasoned judgments about complex problems. Previous studies have emphasized the importance of critical reasoning in climate change education and have shown that problem-oriented or interactive climate-learning approaches can support students' capacity to engage with these demands (Aliyu et al., 2023; Efwinda et al., 2023; Young et al., 2023). The present findings extend this literature by showing that these reasoning processes can be systematically operationalized within a complete instructional package in which climate-related problems, collaborative inquiry, structured worksheets, and virtual representations are organized around an explicit PBL sequence.

The very large effect sizes observed for critical thinking nevertheless require careful interpretation. They indicate a pronounced separation in score change within the present sample, but they should not be assumed to represent the magnitude that would necessarily occur in other populations or implementation settings. The experimental-group posttest scores were concentrated toward the upper end of the scale, and the intervention itself was tightly structured. Accordingly, the findings provide strong evidence of differential improvement under the conditions examined here, while the magnitude of the observed effect requires replication before similar effects can be expected under routine classroom conditions.

Climate change awareness also increased markedly following participation in the learning package. One plausible explanation is that the instructional sequence connected scientific content with contextualized environmental problems and repeatedly required students to consider consequences, mitigation, and personal or collective responses. Effective climate change education has been associated with personally meaningful information, active engagement, and opportunities to consider responses to environmental problems (Carman et al., 2021; Monroe et al., 2019). Scenario-based and participatory learning has also been associated with increased climate-related attitudes and awareness (Álvarez-Nieto et al., 2022; Incesu & Yas, 2024). In this study, the combination of visual representation, problem analysis, collaborative discussion, and reflection may therefore have increased the cognitive and personal salience of climate change for students.

The awareness finding has a different evidential status from the critical-thinking finding. Critical thinking was assessed in both the experimental and control groups, allowing

differential change to be examined directly, whereas awareness was measured only within the experimental group. The significant pretest-posttest increase therefore demonstrates change following participation in the learning package but does not establish that the change was greater than would have occurred under conventional instruction. Moreover, climate change awareness is broader than conceptual knowledge because it includes attitudes, participation, everyday environmental actions, and mitigation-related understanding. Climate change education has consequently been argued to require connections among scientific knowledge, values, decision-making, and action rather than improvement in factual understanding alone (Sharma, 2012; Vaughter, 2016). The observed increase should therefore be interpreted as a meaningful short-term change in reported awareness rather than direct evidence of enduring behavioral change.

The different normalized-gain patterns for critical thinking and awareness can also be understood in relation to the nature of the two constructs. Critical thinking was practiced explicitly and repeatedly throughout the learning sequence through interpretation, analysis, evaluation, explanation, and reflection. Awareness, in contrast, incorporated cognitive, attitudinal, participatory, and action-oriented dimensions. The stronger normalized gain in critical thinking should therefore not be interpreted as evidence that critical thinking was inherently more responsive to the intervention, because the two outcomes were measured using different constructs and scoring structures. Instead, the pattern suggests that cognitive skills directly practiced through structured tasks may show more immediate change during a short instructional sequence, whereas dispositions, participation, and environmental action may require more sustained opportunities for development.

A broader contribution of this study concerns the pedagogical operationalization of virtual reality within a complete PBL learning package. Previous work has proposed a digital pedagogical model combining PBL, climate change education, and virtual reality through phases of orientation, knowledge organization, deep exploration, presentation, and reflection (Suryati et al., 2025). The present study extends that conceptual work by translating those principles into mutually supporting classroom tools and evaluating them in terms of validity, practicality, critical-thinking outcomes, and climate change awareness. Importantly, the findings should not be interpreted as evidence that virtual reality independently produced the observed outcomes. Digital technology is educationally productive when it is subordinated to coherent instructional design and used to support cognitively meaningful activity rather than passive media consumption (Herodotou et al., 2020; Palvia et al., 2018). The contribution of the present study therefore lies primarily in the organization of existing virtual reality media within a structured instructional system.

This interpretation also has practical implications for climate change instruction. Schools do not necessarily need to develop new virtual reality technology to use the approach. Existing third-party videos may serve as useful contextual resources when they are scientifically accurate, relevant to curricular objectives, accessible to students, and connected to learning activities that require investigation, evaluation, discussion, and reflection. Structured teaching modules and worksheets remain essential because they provide teachers and students with a clear instructional pathway through these activities. Previous studies have similarly emphasized the importance of systematically designed learning materials for supporting active and technology-enhanced climate change instruction (Arila, 2023; Mufidah et al., 2023). The practical value of the package therefore lies less in technological novelty than in providing a coherent way to connect climate science, authentic problem solving, collaborative reasoning, and digital visualization.

Limitation

This study has several limitations that should be considered when interpreting the findings. First, the study involved only 40 purposively selected students from a single school, which limits the generalizability of the findings to broader student populations and educational contexts. The instructional intervention was also conducted over only two instructional meetings, making it difficult to determine whether the observed improvements in critical thinking and climate change awareness would be sustained over a longer period. In addition, the researcher served as the instructor during implementation. Although this arrangement supported consistency and fidelity in delivering the learning package, implementation by teachers who were not directly involved in its development may produce different results under routine classroom conditions. The relatively concentrated posttest score distributions, particularly in the experimental group, should also be considered when interpreting the very large effect sizes observed in the statistical analyses.

Second, the intervention consisted of multiple interconnected components, including PBL, virtual reality videos, student worksheets, collaborative problem solving, presentation, and reflective discussion. Consequently, the present design does not allow the contribution of each component to be isolated independently. Climate change awareness was also assessed only in the experimental group; therefore, the observed pretest-posttest increase cannot be interpreted as a comparative intervention effect relative to conventional instruction. Furthermore, the awareness questionnaire demonstrated comparatively lower content validity than the other developed learning tools, indicating a need for further refinement of its content representation. Future research should replicate the learning package with larger and more diverse samples across multiple schools and teachers, extend the duration of implementation, include delayed posttests to examine retention, collect climate change awareness data from both experimental and control groups, and further refine the awareness instrument. Future studies could also examine whether improvements in reported awareness are accompanied by observable changes in students' environmental practices and whether specific components of the integrated learning package contribute differently to learning outcomes.

CONCLUSION

This study developed and evaluated a problem-based learning package integrating pre-existing virtual reality videos for Grade X climate change instruction. The package consisted of a teaching module, student worksheet, instructional materials, a critical-thinking assessment, and a climate change awareness questionnaire. Overall, the developed learning tools met the required content- and construct-validity criteria and were practically implementable in classroom instruction, as reflected in the successful enactment of all five PBL phases, active student participation, and high agreement between observers. Although the climate change awareness questionnaire showed comparatively lower content validity than the other components, its construct validity met the established criterion, indicating that the package as a whole provided a sufficiently coherent instructional system for classroom implementation.

The learning outcomes further indicate that students who participated in the PBL learning package integrating virtual reality videos demonstrated greater improvement in critical thinking than students receiving conventional expository instruction. Improvement occurred across interpretation, analysis, evaluation, inference, explanation, and self-regulation, with the significant Group $\times$ Time interaction confirming a substantially different pattern of change between groups. Climate change awareness also increased from low to high

within the experimental group, although this finding represents a within-group pretest-posttest change rather than a comparative intervention effect. Collectively, the findings demonstrate the pedagogical potential of organizing existing virtual reality media within a structured PBL sequence that connects climate science with problem exploration, collaborative reasoning, presentation, and reflection. The contribution of the study therefore lies in the development and empirical evaluation of an integrated instructional package rather than in the independent effect of virtual reality technology.

RECOMMENDATIONS

The developed PBL learning package may be considered for climate change instruction when virtual reality videos are deliberately integrated with structured problem exploration rather than used as stand-alone media. Teachers should select scientifically accurate and curriculum-relevant virtual reality resources and connect them with worksheets, collaborative inquiry, evidence evaluation, presentation, and reflective discussion. Further studies should evaluate the package with larger and more diverse samples across multiple schools and teachers, extend the duration of implementation, include delayed posttests to examine retention, and collect climate change awareness data from both experimental and control groups. Further refinement of the awareness questionnaire is also recommended, together with investigations of whether increased reported awareness translates into sustained environmental practices and whether specific components of the learning package contribute differently to student outcomes.

Author Contributions

The authors have sufficiently contributed to the study, and have read and agreed to the published version of the manuscript.

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Declaration of Interest

The author declares no conflict of interest.

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