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Problem-Based Learning in Remote Learning Scenario Utilizing Climate Change Virtual Reality Video in Mobile Application to Train Critical Thinking

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Abstract

The imperative to address climate change in educational curricula stems from its profound implications for the sustainability of human life. A crucial aspect of this education is fostering critical thinking (CT) in students, as they form their perspectives on climate change. Traditional teaching approaches alone have proven inadequate in developing students' CT concerning this complex issue, particularly when learning remotely. To address this challenge, students must be actively engaged with the realities of climate change. In response to this need, the current study aimed to apply the problem-based learning (PBL) in remote learning scenarios utilizing climate change virtual reality (VR) video in mobile application to train students' CT skills. Utilizing a mixed method approach, the study involved 86 high school students, divided evenly between experimental and control groups, using a 'true experimental design' to quantify CT skill improvements. Complementing the quantitative data, the study also conducted semi-structured interviews with teachers participating in the interventions, providing valuable insights into their responses to the learning methods. The instruments used to measure students' CT skills were carefully validated for psychometric properties (validity and reliability). The study's overall findings indicate that the PBL approach integrated with climate change VR videos in mobile applications effectively enhances students' critical thinking skills, surpassing the outcomes of traditional teaching methods. Moreover, the feedback received from teachers who participated in the teaching interventions was overwhelmingly positive, reinforcing the efficacy of the learning approach. This research highlights the significance of implementing PBL and VR experiences to cultivate CT among students, particularly in the context of climate change education.

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INTRODUCTION

In recognition of the vital importance of climate change and its implications for the sustainability of human life, educational institutions are increasingly incorporating critical issues related to this topic into their learning curricula (Bleazby et al., 2023). By doing so, educators aim to foster a generation of students equipped with critical thinking (CT) skills in their approach to understanding and addressing climate change (Young et al., 2023). It has become evident that traditional teaching methods centered solely on conveying information about climate change are no longer sufficient to cultivate students' critical thinking abilities and their awareness of climate change (Hillary et al., 2023). In response to the complexities and challenges posed by climate change, a more dynamic and immersive approach to learning is needed.

The advent of remote learning further accentuates the need to evolve pedagogical strategies for climate change education (Newsome et al., 2023). In a virtual learning environment, the risk of stunting students' critical thinking growth becomes more pronounced. Mere transmission of information through online platforms does not effectively stimulate the kind of deep engagement necessary for nurturing robust CT skills (Sollied Madsen et al., 2021). Students require experiential learning opportunities that allow them to delve into the realities of climate change, encouraging active participation and critical exploratory (Minan et al., 2021).

To address these educational challenges and bridge the gap between climate change knowledge and critical thinking development, a novel intervention is proposed. The current study seeks to implement problem-based learning (PBL) in remote learning scenario utilizing a climate change virtual reality (VR) video in a mobile application. By leveraging the immersive capabilities of VR technology, students can be virtually transported to various scenarios depicting real-world impacts of climate change (Meijers et al., 2023). This hands-on and interactive approach empowers students to explore complex problems, consider diverse perspectives, and propose informed solutions. Through the application of PBL in combination with VR, we aim to enhance students' CT skills while instilling a deeper understanding of the urgency surrounding climate change. Recent studies have demonstrated the beneficial effects of integrating attractive and interactive digital technology into teaching methods, leading to expanded student learning outcomes (Verawati, Handriani, et al., 2022). Additionally, such methods have shown promise in nurturing students' thinking abilities (Bilad et al., 2022). Notably, in the realm of science education, the use of assistive technology in mobile application to tackle real-world problems has been associated with advanced critical thinking skills among students (Suhirman & Prayogi, 2023).

By directly engaging with climate change issues through VR simulations, students can cultivate a heightened sense of empathy and responsibility toward the environment and society. Moreover, this intervention promotes a more profound connection between theoretical knowledge and its practical implications, empowering students to become active agents of change in combating climate change. As students develop into critical thinkers with a strong grasp of climate-related complexities, they are better equipped to tackle global challenges, devise sustainable solutions, and advocate for meaningful policy changes (Kavanagh et al., 2021). Integrating problem-based learning and virtual reality technology into climate change education is a promising step towards nurturing a generation of informed, critical thinking, and environmentally conscious individuals who can contribute to a more sustainable future.

Referring to the justification of the aforementioned problems, the current study aimed to apply the PBL in remote learning scenario utilizing climate change VR video in mobile application to train students' CT skills. Specifically, the research questions are as follows.

- What is the impact of using PBL in remote learning scenario that utilizes climate change VR video in mobile application on improving students' CT skills?
- What is the teacher's response during the learning process using the PBL in remote learning scenario that utilizes climate change VR video in mobile application?

LITERATURE REVIEW

Critical Thinking Skills

In the modern education system, the primary responsibility of educational institutions is to equip students with Critical Thinking (CT) skills (Erikson & Erikson, 2019). CT is considered a driving force behind improved academic performance (D'Alessio et al., 2019; Siburian et al., 2019). To achieve this, there is a growing emphasis on incorporating CT teaching methods in classrooms using contemporary approaches (Dekker, 2020). Developed countries increasingly view CT as an essential competency at all levels of education (Szenes et al., 2015), as it is believed that students' proficiency in CT directly influences the quality of education (Gilmanshina et al., 2021).

CT, often defined as "reasonable and reflective thinking, focused on decision-making and belief formation" (Ennis, 2018), involves deep reasoning in the cognitive or intellectual dimension (Elder & Paul, 2012). The ability to reason is a fundamental goal of various instructional methods within the classroom setting. CT skills serve as cognitive bridges in problem-solving processes (Evendi et al., 2022). Researchers in educational psychology commonly highlight the significance of CT competencies in learners, with indicators such as analyzing, inferring, evaluating, and decision-making being heavily examined in various studies (Prayogi et al., 2022; Verawati, Ernita, et al., 2022; Wahyudi et al., 2018).

Effectively training students in CT requires innovative learning interventions, as not all instructional methods are suitable for this purpose (Prayogi et al., 2018). One of the unique and effective ways to foster CT skills is through Problem-based Learning (PBL), where students engage in exploring and experimenting to solve problems (Suhirman et al., 2020). This approach allows students to apply critical thinking in practical contexts and develop their problem-solving abilities.

Problem-Based Learning

The PBL approach is a pedagogical model that encourages students to investigate authentic problems and explore potential solutions (Evendi et al., 2022). This method follows distinct learning phases, which include student orientation to real-world problems, organizing students for learning, engaging in investigative processes to solve the problems, presenting the investigation results, and reflecting on the problem-solving outcomes (Evendi et al., 2022). Presenting authentic problems and encouraging investigative problem-solving not only leads to the emergence of new knowledge products (Hung, 2011) but also enhances knowledge retention and promotes a deeper understanding of concepts (H.-C. Li & Tsai, 2017). Additionally, incorporating the PBL pedagogy into learning content positively influences students' reasoning performance (Wirkala & Kuhn, 2011), particularly in achieving critical thinking (CT) skills, as exploration and investigation foster CT development (Calkins et al., 2020).

The flexible nature of the PBL model allows for its application in various ways, including leveraging digital environments such as e-learning platforms (e-PBL) (Evendi et al., 2022). Utilizing e-PBL has been found to effectively enhance students' CT skills across different cognitive styles of learners (Evendi et al., 2022). Moreover, studies investigating mobile blended PBL have shown positive outcomes, indicating improved problem-solving skills (Amin et al., 2021). Notably, when PBL is implemented in blended learning, its core functions and principles remain intact (de Jong et al., 2017). Furthermore, researchers have explored innovative approaches, such as cloud-based PBL, to enhance students' digital skills and creative thinking (Srikan et al., 2021). In one specific study, assistive virtual simulation in a mobile application was utilized to intervene in PBL and assess its impact on students' CT skills (Suhirman & Prayogi, 2023).

Virtual Reality

Virtual reality (VR) is a technology that creates a simulated reality within a virtual environment, enabling users to fully immerse themselves and interact with three-dimensional models (Bereczki & Kárpáti, 2021). This immersive experience offers greater autonomy, interaction, and realism compared to standard computer use (S. Chang et al., 2020). From a constructivist perspective, VR has the potential to bridge the gap between theoretical knowledge and real-life experiences, benefiting learners (Huang & Liaw, 2018). Researchers have observed several positive impacts of VR usage, including improved problem-solving skills for open-ended issues (Huang et al., 2010), enhanced critical thinking abilities (S. Chang et al., 2020), and increased aptitude for active exploration (Gloy et al., 2022). However, the literature also highlights some disadvantages of immersive technology, such as cognitive overload (Hsu, 2017), and potential issues with learning effectiveness (Jensen & Konradsen, 2018).

In recent times, educators have been utilizing immersive media, like VR, in various educational contexts. This has caused a paradigm shift in education and training (S. Chang et al., 2020). Some researchers propose that immersive technology could expand the boundaries of formal education (Martín-Gutiérrez et al., 2017) and offer an alternative to traditional training methods (Morélot et al., 2021). Furthermore, immersive media is seen as an emerging learning tool that enhances interest, happiness, and creativity in education (Ferguson, 2011). Studies have also shown that immersive media can positively influence learners' knowledge, motivation, and cognition (Singh et al., 2021), leading to various applications in open education, science education, and beyond (K. Li & Wang, 2021; Parong & Mayer, 2018). As the interest in immersive media grows, researchers increasingly examine its impact on students through scientific experimentation (Lai et al., 2022). It has been observed that immersive technologies can enhance students' emotional engagement in online communities (Wang & Sun, 2021). Additionally, students' cognitive absorption in these new media environments plays a crucial role in their learning performance (Reychav & Wu, 2015). Current study to evaluate the impact of VR video in mobile application in the climate change context to train students' CT skills.

METHODS

Research Design

This research utilizes a mixed method approach, which integrates both quantitative and qualitative data to attain a comprehensive understanding of the subject. Specifically, an explanatory sequential design is employed, representing a type of mixed method research that effectively combines diverse data sources (Creswell & Creswell, 2018). By employing this approach, the study addresses potential limitations associated with relying solely on quantitative or qualitative analyses. In this study, data collection involved the application of quantitative measurement within an experimental framework. Additionally, qualitative data was gathered and analyzed in conjunction with the quantitative results to enhance and provide further insights. The quantitative study utilized a true experimental approach (Fraenkel et al., 2012). The purpose of this design was to accurately assess the impact of a controlled learning intervention. Two distinct groups were formed for the study, the treatment group and the control group. Details of this design in the Table 1.

Table 1. Design of the study

Group	Pre-test	Intervention	Post-test
Treatment	O_1	X_1 (PBL utilizing climate change VR video in mobile application)	O_2
Control	O_1	X_2 (Traditional teaching)	O_2

The treatment group received a learning intervention based on PBL in remote learning scenario that utilizes climate change VR video in mobile application. On the other hand, the control group received traditional teaching methods. The assessment of CT skills was conducted for both groups, with a pretest administered before the learning intervention and a posttest administered after. The actual learning sessions, excluding the pretest and posttest, consisted of fourth meetings, each lasting approximately 2 x 45 minutes, where the topic of climate change was covered. Notably, the pretest, learning intervention, and posttest were all scheduled concurrently, deliberately organized in this manner to eliminate potential bias.

During the qualitative phase, educators were engaged in interviews to elicit their viewpoints regarding the ongoing learning process. These interviews were performed subsequent to the implementation of the learning program, with the objective of gaining profound insights into its impact. Valuable perspectives on the effectiveness of the learning initiatives were sought from teachers through semi-structured interviews.

Participants

The students served as research samples and were selected from a senior high school in Nigeria. A total of 86 students were included in the study, and they were evenly divided into two groups - the treatment group (n = 43) and the control group (n = 44). It is essential to mention that prior to the learning intervention, the treatment group had no prior experience with PBL in remote learning scenario utilizing climate change VR videos through a mobile application. For further details regarding the participant demographics, refer to Table 2.

Table 2. Demographics of participant

Characteristics		Treatment group		Control group	
		n	%	n	%
Gender	Male	21	48.84	22	51.16
	Female	22	51.16	21	48.84
	Total	43	100	43	100
Age (year)	< 15	1	2.36	0	0
	15 – 16	41	95.28	43	100
	> 16	1	2.36	0	0
	Total	43	100	43	100

Instruments and Psychometric Properties

In order to support the implementation of the study, various learning tools were prepared, including e-modules, learning scenarios, interview guidelines, and CT skills tests. The CT skills test consisted of eight items designed to assess analytical, inference, evaluation, and decision-making abilities. Before utilization, it was essential for the learning instruments to meet adequate psychometric standards. Ensuring the validity and reliability of the instrument was crucial as a prerequisite for its continuous implementation (Souza et al., 2017). The validation of the learning instrument was performed with the help of two science learning experts who possessed substantial experience in designing science lessons and had over a decade of teaching experience in the field. These validators meticulously assessed the instrument's validity and provided valuable feedback, resulting in a descriptive analysis of the validation outcomes. The results indicated that the learning instrument was valid both in terms of content and construct domains (Akker et al., 2013). In the validation process, the reliability of the learning instrument was also determined, referring to the level of consistency of the instrument based on the extent of its validity. The percentage of agreement parameter was used to gauge reliability (Emmer & Millett, 1970). Based on the outcomes of this reliability test, it was established that the learning instrument was reliable and feasible to be utilized as a valuable learning support.

Data Analysis

The data regarding students' CT skills were obtained using a validated CT skill test instrument. To assess CT, a pretest and posttest in the form of an essay, consisting of eight item questions, were administered. Each test item was scored on a graded scale, ranging from -1 (minimum) to +3 (maximum), based on criteria that covered a spectrum from not critical to very critical. By summing up individual scores on the CT test, the cumulative performance of each student's CT skills was determined. This follows the principles of previous studies (Prayogi et al., 2018; Suhirman & Prayogi, 2023).

The researchers conducted an analysis of the students' CT skills data (pretest and posttest) for both the treatment and control groups. The analysis included both descriptive and statistical methods. To measure the improvement in students' CT skills from pretest to posttest (n-gain), they adopted Hake's formulation (Hake, 1999) and categorized the results into three groups: low (<0.3), moderate (0.3 – 0.7), and high (>0.7). Furthermore, they used statistical analysis (differential test) to assess the differences in students' CT performance between the treatment and control groups. The significance level for the statistical tests was set at 0.05. The software JASP_0.17.3 was employed for conducting the statistical analysis.

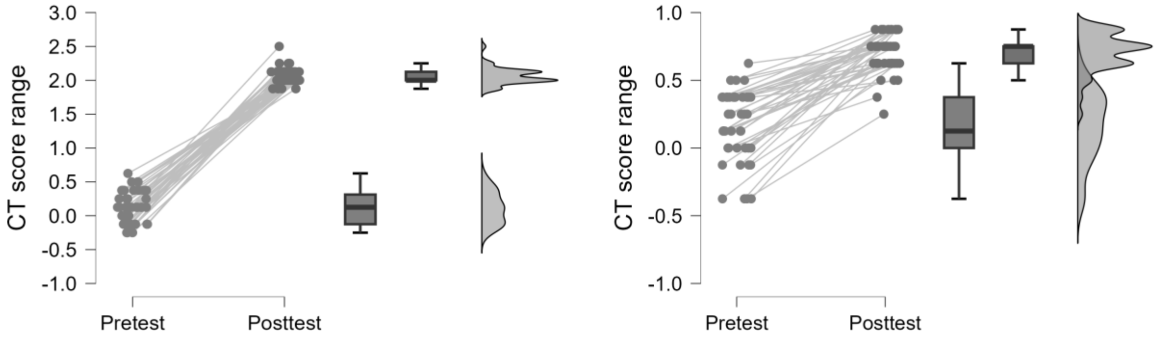
To examine the qualitative data acquired from the teacher interview forms, we conducted a content analysis on the transcripts. The information gathered from the teachers' responses regarding the learning implementation offers significant findings that complement the quantitative results.

RESULTS AND DISCUSSION

A study has been conducted which aims to apply the PBL in remote learning scenario utilizing climate change VR video in mobile application to train students' CT skills. Measurement of students' CT skills was carried out before and after the learning intervention in the treatment and control groups. The results are presented in Table 3. Descriptive plots of increasing CT scores from pre-test to post-test for treatment and control groups can be seen in Figure 1.

Table 3. CT measurement results in the treatment and control groups

Groups	Measurement	N	Mean	SD	SE	n-gain <g>	Criteria
X_1	O_1 (Pre-test)	43	0.113	0.236	0.036	0.67	Moderate
(Treatment)	O_2 (Post-test)	43	2.058	0.120	0.018		
X_2 (Control)	O_1 (Pre-test)	43	0.160	0.258	0.039	0.19	Low
	O_2 (Post-test)	43	0.706	0.141	0.022		



(a) (b)

Figure 1. Descriptive plots of increasing CT scores from pre-test to post-test for: (a) treatment group, (b) control group

In the results of Table 3 and Figure 1, two groups of students were examined to assess their critical thinking (CT) skills. The treatment group showed a notable improvement in CT skills from the pre-test, where their scores were in the 'less critical' range (M = 0.133, SD = 0.236), to the post-test, where they achieved 'critical' levels (M = 2.058, SD = 0.120). The observed increase in the CT scores (n-gain) for the treatment group was considered 'moderate,' with a size of <g> = 0.67. On the other hand, the control group also started with CT skills in the 'less critical' range during the pre-test (M = 0.160, SD = 0.258). However, their post-test scores indicated an improvement, reaching 'quite critical' levels (M = 0.706, SD = 0.141). Nevertheless, the increase in the CT scores for the control group was deemed 'low,' with a size of <g> = 0.19. These findings highlight the efficacy of the treatment (apply the PBL in remote learning scenario utilizing climate change VR video in mobile application) in enhancing critical thinking skills compared to the control group's progress.

Furthermore, the difference in the average score of CT skills for each group was analyzed using ANOVA. The results are presented in Table 4. Post hoc comparisons between groups with the pre- and post-test average parameters are presented in Table 5.

Table 4. Results of analysis of variance between groups

Within Subjects Effects	**Sum of Sqr.**	**df**	**Mean Sqr.**	**F**	**p**	**η²**
CT ($O_1 - O_2$)	66.720	1	66.720	1764.089	< .001	0.592
CT ✻ Int. groups ($X_1 - X_2$)	21.018	1	21.018	555.711	< .001	0.187
Residuals	3.177	84	0.038			
Between Subjects Effects						
Int. groups ($X_1 - X_2$)	18.314	1	18.314	452.842	< .001	0.163
Residuals	3.397	84	0.040			

The analysis presented in Table 4 reveals compelling findings regarding the impact of the interventions on critical thinking (CT) scores. A noteworthy outcome is the significant difference observed in CT scores between the pre-test (O_1) and post-test (O_2) in both intervention groups (treatment and control). This difference is evidenced by the considerable F-value of 1764.089 ($p < 0.001$), which indicates a high level of statistical significance. Moreover, the effect size, represented by $\eta^2 = 0.592$, demonstrates that 59.2% of the variability in the CT scores can be attributed to the intervention.

Furthermore, the investigation delves deeper into the comparison of CT scores ($O_1 – O_2$) between the treatment groups (X1 – X2). The results indicate another statistically significant finding, with an F-value of 555.711 ($p < 0.001$). The effect size for this comparison is $\eta^2 = 0.187$, signifying that 18.7% of the variance in CT scores can be attributed to the distinctions between the treatment groups. This indicates that different interventions had a considerable impact on participants' critical thinking abilities. Additionally, the study also explored the differences between the treatment groups ($X_1 – X_2$) independently, revealing yet another significant result with an F-value of 452.842 ($p < 0.001$) and an effect size of $\eta^2 = 0.163$. This highlights that the specific interventions themselves had a substantial effect on participants' CT scores. Overall, the analysis underscores the effectiveness of the interventions in enhancing students' CT skills.

Table 5. Post hoc comparisons between groups

Groups		Mean Diff.	SE	t	Cohen's d	p
X_2 (O_1)	X_1 (O_1)	0.047	0.043	1.090	0.235	0.277
	X_2 (O_2)	-0.547	0.042	-13.030	-2.763	< .001
	X_1 (O_2)	-1.898	0.043	-44.495	-9.596	< .001
X_1 (O_1)	X_2 (O_2)	-0.593	0.043	-13.900	-2.998	< .001
	X_1 (O_2)	-1.945	0.042	-46.368	-9.831	< .001
X_2, (O_2)	X_1 (O_2)	-1.352	0.043	-31.685	-6.833	< .001

The analysis conducted on the data revealed noteworthy insights regarding the students' CT skills in relation to the treatment and control groups. Initially, prior to the implementation of the learning intervention, it was observed that there was no statistically significant difference in the CT pre-test scores (O_1) between the treatment (X_1) and control (X_2) groups. This finding suggests that, at the outset, both groups exhibited comparable levels of CT capabilities. This similarity in CT scores indicates that any subsequent disparities in performance cannot be attributed to inherent differences in their baseline abilities, but rather to the impact of the learning intervention itself.

Subsequently, the post hoc comparisons between other groups yielded intriguing results. Notably, significant differences were observed in CT scores between various groups across all test categories, including both pre-test (O_1) and post-test (O_2) assessments. This implies that the learning intervention had a discernible influence on students' CT skills, leading to divergent outcomes among different groups. These discrepancies be indicative of varying degrees of responsiveness to the intervention or differences in the instructional approaches utilized. Moreover, the notable improvements in CT scores observed in the post-test phase (O_2) further underscore the efficacy of the learning intervention in enhancing students' CT skills.

After the learning intervention in the treatment group, the researchers conducted semi-structured interviews with the teachers who participated in the teaching. The results of the interview transcripts and recordings revealed three main aspects: firstly, learning intervention provided convenience for teachers in the learning process; secondly, learning intervention positively impacted student motivation; and thirdly, learning intervention increased student engagement.

Learning intervention provided convenience for teachers in the learning process. *"The interventions using the climate change VR video in the mobile application have been incredibly helpful. Firstly, it allowed me to bring a real-life experience of climate change impacts into the classroom,* *making the concepts more tangible and engaging for my students. The convenience lies in the ease of access; students can use their own mobile devices, reducing the need for additional equipment. Additionally, the PBL approach encouraged students to explore and research independently, promoting critical thinking and problem-solving skills. The mobile application also facilitated seamless collaboration among students, enabling them to work together on projects effortlessly. Overall, these interventions have enhanced the learning experience, making it both convenient and enriching for both me and my students."*

Learning intervention positively impacted student motivation. *During the PBL sessions with the climate change VR video, I noticed a remarkable increase in student engagement and motivation. The immersive nature of the VR experience allowed students to connect with the topic on a deeper level, and they were more eager to explore and understand complex concepts."*

Learning intervention increased student engagement. *"During the learning process with the PBL and VR video, I observed a significant increase in student engagement compared to traditional teaching methods. The immersive nature of the VR video captured their attention and stimulated their curiosity about climate change. The students actively participated in problem-solving activities, drawing connections between the VR experience and real-world scenarios. They were excited to explore different aspects of the topic, discussing and brainstorming solutions collaboratively. Moreover, the mobile application provided accessibility, allowing students to continue their engagement outside the classroom."*

In this particular investigation, the acquisition of critical thinking has been accomplished through the utilization of Problem-Based Learning (PBL) in remote learning settings, employing VR videos related to climate change within mobile applications. The purpose of this approach is to enhance students' Critical Thinking (CT) abilities. The PBL approach for this study adheres to the guidelines outlined by Suhirman and Prayogi (2023), specifically tailored to the subject of climate change, and encompasses several distinct stages: (a) Familiarizing students with climate change issues; (b) Organizing the learning process effectively; (c) Investigations concerning climate change topics; (d) Presenting the findings from climate change inquiries; and (e) Reflecting on problem solving. Throughout this process, the climate change VR videos within the mobile application serve as both a guide and a valuable tool. They aid students in comprehending the intricacies of climate change while actively participating in the investigative aspects of their learning journey. Climate change VR videos are rendered from global environmental authorities who have prepared platforms on issues related to climate change, such as the United Nations Environment Program (UNEP) (https://www.unep.org). Figure 2 showcases various VR videos depicting climate change scenarios.

Figure 2. Climate change VR videos rendered from UNEP (https://www.unep.org).

The adaptability of problem-based learning (PBL) makes it compatible with mobile applications. Previous research has demonstrated that employing mobile PBL applications can effectively enhance students' CT abilities (Ismail et al., 2018). Referring to the findings of the current study, PBL is a powerful educational approach that encourages students to actively engage with real-world challenges (Albar & Southcott, 2021). When implemented in remote learning scenarios with the aid of climate change VR videos in mobile applications, it can significantly enhance students' CT skills. This combination provides a unique and immersive learning experience, fostering students’ CT skills. Climate change VR videos offer a realistic and interactive environment, allowing students to experience the consequences of climate change firsthand, as the experience of previous studies (Queiroz et al., 2023). This immersive experience triggers students’ curiosity and prompts them to identify problems and potential solutions (Thoma et al., 2023). By presenting complex issues in a tangible and engaging manner, students are encouraged to think critically about the causes and implications of climate change, leading them to analyze various perspectives and formulate informed opinions.

PBL in combination with climate change VR videos facilitates active learning. Instead of passively receiving information, students are actively involved in the learning process (Cho & Park, 2023). PBL tasks present them with authentic challenges related to climate change, requiring them to research, analyze data, and collaborate with peers to find viable solutions. This active engagement stimulates their critical thinking abilities, as they must synthesize information, draw connections, and make reasoned judgments. Furthermore, the integration of mobile applications adds flexibility and convenience to the learning process, especially in remote settings. Students can access VR videos and participate in PBL activities at their own pace, fostering self-directed learning and ownership of their education. The mobile platform also allows for continuous feedback and reflection (Ekici & Erdem, 2020), enabling students to assess their progress and refine their critical thinking skills throughout the learning journey (Ninghardjanti & Dirgatama, 2021).

PBL with climate change VR videos encourages critical thinking. Climate change is a complex issue that involves various disciplines such as science, environment, and ethics. By immersing students in the multidimensional aspects of climate change through VR videos, PBL fosters cross-disciplinary connections, prompting students to approach problems from different angles. This interdisciplinary approach nurtures their ability to think critically and holistically, preparing them to address real-world challenges that demand integrated solutions. Several previous studies have shown the advantages of VR video in problem solving ways to improve learning performance (C.-Y. Chang et al., 2022), and higher order thinking skills (Hwang et al., 2022). Even in the specific context of PBL, the presence of VR technology has a significant impact on motivation and problem-solving performance (Chen et al., 2021).

In conclusion, the combination of Problem-based Learning (PBL) in remote learning scenarios with climate change VR videos in mobile applications has the potential to significantly train students' critical thinking (CT) skills. The immersive nature of VR videos, coupled with active learning and self-direction in PBL, encourages students to think critically about climate change and its impact on the world. Furthermore, the interdisciplinary aspect of PBL with VR videos broadens their perspectives, enabling them to tackle real-world challenges with a well-rounded approach. By leveraging these educational tools, educators can empower students to become informed and critical thinkers, equipped to contribute meaningfully to the global effort in addressing climate change and other complex issues.

CONCLUSION

Overall, the findings suggest that the learning intervention with PBL in remote learning scenario utilizing climate change VR video in mobile application effectively enhanced students' critical thinking skills compared to traditional teaching methods. The findings from the study provide several key insights: (a) The treatment group, which received the learning intervention, showed a notable improvement in CT skills from the pre-test to the post-test. Their scores increased from being in the 'less critical' range to achieving 'critical' levels. The observed increase in CT scores (n-gain) for the treatment group was considered 'moderate,' indicating the effectiveness of the intervention. (b) The control group also demonstrated an improvement in CT skills from the pre-test to the post-test, moving from the 'less critical' range to 'quite critical' levels. However, the increase in CT scores for the control group was deemed 'low' compared to the treatment group. (c) The analysis of variance (ANOVA) revealed significant differences in CT scores between the pre-test and post-test for both intervention groups. Additionally, the effect size indicated that a considerable portion of the variability in CT scores could be attributed to the interventions, highlighting their impact on students' CT skills. (d) Post hoc comparisons further supported the effectiveness of the learning intervention, showing significant differences in CT scores between different groups, indicating varying degrees of responsiveness to the intervention or differences in instructional approaches. (e) The interviews with teachers who participated in the teaching revealed positive feedback about the learning intervention. Teachers found it convenient to use the climate change VR video in the mobile application, enhancing the learning experience and promoting critical thinking and problem-solving skills. The intervention also positively impacted student motivation and increased their engagement with the topic.

LIMITATION

One of the limitations of this study is related to the generalizability of the findings. The study focused exclusively on a specific group of high school students and teachers in a controlled educational environment. The findings might not fully capture the potential variations in critical thinking skill development across diverse student populations or in different educational settings. Additionally, the study's short-term nature may not account for potential long-term effects or sustainability of the observed improvements in critical thinking skills. Thus, while the results are promising within the context of climate change education using problem-based learning and virtual reality, caution should be exercised when applying these findings to broader educational contexts and age groups.

RECOMMENDATION

While this study successfully demonstrated the effectiveness of problem-based learning (PBL) integrated with climate change virtual reality (VR) videos in enhancing students' critical thinking skills in the remote learning scenario, there are several avenues for future research that could further enrich the field of climate change education and pedagogical practices. Firstly, a longitudinal study could be conducted to assess the long-term retention and application of critical thinking skills acquired through this approach. Secondly, investigating the influence of various factors such as students' prior knowledge, socio-economic backgrounds, and technological proficiency on the outcomes of PBL and VR integration could provide insights into tailoring the approach to diverse student populations. Additionally, comparative studies across different subjects or disciplines could shed light on the transferability of this approach beyond climate change education. Lastly, exploring the potential of collaborative PBL in virtual reality settings could offer a novel dimension to student engagement and critical thinking development.

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 authors declare no conflict of interest.

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