International Journal of Emerging Research and Review
Homepage : https://ijoerar.net/index.php/ijoerar
p-ISSN : 3024-8825; e-ISSN : 3021-8950

IJOERAR, Vol. 3, No. 3, September 2025

Development of a VR-based E-Book to Enhance Science Literacy Skills in Elementary School Students

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DOI: https://doi.org/10.56707/ijoerar.v3i3.117

Sections Info

Article history:
Submitted: May 1, 2025
Final Revised: May 22, 2025
Accepted: May 27, 2025
Published: June 3, 2025

Keywords:
Science literacy
E-book
Virtual reality
Material development
Water Cycle

ABSTRACT

Objective: *This study aimed to develop a Virtual Reality (VR)-based E-Book that is valid, practical, and effective in enhancing science literacy in elementary school students, specifically focused on the topic of the water cycle.* ***Method:*** *The research used a Research and Development (R&D) method with the 4-D model (Define, Design, Develop, Disseminate). The study was conducted with fifth-grade students at SDN Lontar II Surabaya. Data were collected through expert validation, observations of the lesson implementation, student response questionnaires, and science literacy tests.* ***Results:*** *The VR-based E-Book was found to be highly valid, with an average validity score of 92.5%. It was also highly practical, with a lesson implementation score of 93% and a positive student response rate of 91%. Additionally, the E-Book effectively improved science literacy, as evidenced by higher post-test scores compared to pre-test scores, with an N-gain of 0.73, indicating a high level of effectiveness.* ***Novelty:*** *This research introduces an innovative approach to science learning through the use of VR technology, providing an interactive and engaging way to teach complex concepts like the water cycle. The VR-based E-Book contributes to the development of technology-enhanced learning tools, offering a new media alternative for science education in elementary schools.*

INTRODUCTION

The advancement of science and technology has significantly impacted education systems worldwide, including in Indonesia. As technological progress accelerates, education must adapt to stay relevant and effective. In this context, the role of teachers becomes crucial in designing learning activities that are not only informative but also engaging, aiming to develop skills aligned with 21st-century demands (Kimianti & Prasetyo, 2019). The four major 21st-century skills, literacy, creative thinking, effective communication, and high productivity, serve as fundamental competencies for individuals to navigate the dynamic challenges of modern society (Shofiyah et al., 2020). In science education, literacy, particularly scientific literacy, is essential. Scientific literacy encompasses reading, comprehending, and interpreting scientific information, fostering scientific understanding and effective communication.

Scientific literacy is more than mere mastery of concepts; it also involves cultivating scientific attitudes and effectively conveying research findings to society. Strengthening scientific literacy aims to produce generations capable of articulating scientific ideas and contributing to broader knowledge dissemination (Nofiana & Julianto, 2018). In today's rapidly evolving world, scientific literacy is not a luxury but a necessity. It involves applying scientific knowledge to real-world contexts, posing scientific questions, constructing explanations based on evidence, and reflecting critically. This ability equips

individuals with the competence to make informed decisions and solve complex problems (Robbia & Fuadi, 2020).

Scientific literacy can be classified into four categories: (1) science as knowledge, (2) science as an investigative process, (3) science as a way of thinking, and (4) the interaction of science with environment, technology, and society. These elements collectively ensure that science education becomes theoretical and practically impactful in daily life (Azimi et al., 2017). The 2022 PISA results revealed a significant improvement in Indonesian students' scientific literacy, reading, and mathematics compared to 2018. Indonesia climbed six positions in scientific literacy, marking its best performance since its participation in PISA. This achievement reflects the resilience of Indonesia's education system in overcoming the learning loss triggered by the pandemic.

Despite these improvements, sustained efforts are necessary to maintain and further enhance science education in schools. Responding to these needs, the researcher proposes the development of a Virtual Reality (VR) based E-Book for science learning to bolster students' scientific literacy and foster deeper engagement with scientific concepts. Several factors contribute to the low scientific literacy among students, including outdated curricula, unengaging teaching methods, and irrelevant learning materials. These inadequacies hinder students' ability to keep up with scientific advancements and emphasize the urgent need for innovation in educational practices (Juniati et al., 2020).. In this context, teachers play a pivotal role as designers of students' futures. As professional designers, teachers are expected to shape students into better, more qualified individuals who are ready to actively participate in future life (Nurwiatin, 2022).

Creativity becomes a crucial character trait in education, especially with the ongoing integration of technology that defines the emergence of Education 4.0. This creative character enables students and educators alike to grow and adapt in tandem with the relentless pace of global technological innovation (Putri Supriadi et al., 2022). Through such creativity, learning tools that incorporate immersive technologies like Virtual Reality stimulate scientific thinking and prepare students to thrive in a world increasingly shaped by Industry 4.0 and Society 5.0 dynamics.

Low scientific literacy causes students to be less responsive to environmental changes, struggle with problem-solving, and be slow in decision-making. Contributing factors include poor understanding of basic science concepts, conventional teaching methods, weak skills in reading graphs or tables, low interest in reading, and the neglect of reading and writing as essential competencies (Yusmar & Fadilah, 2023). This highlights the urgent need for innovation in science learning approaches and media in schools.

Teachers play a crucial role in utilizing learning media; however, it is undeniable that some educators still face difficulties in using such tools effectively. Several challenges hinder teachers from developing and implementing instructional media, including: (1) lack of knowledge on how to use educational media, (2) the cost involved in producing the media, and (3) the complexity of the subject matter, which makes it difficult for teachers to design appropriate media. These problems often stem from teachers' limited understanding of learning media development. Nevertheless, the teacher's role in integrating media into the teaching process has a significant positive impact. It not only

facilitates students' learning but also allows teachers to explore effective teaching strategies and apply diverse learning models to achieve optimal learning outcomes (Mukarromah & Andriana, 2022).

As educators, it is essential to shift our mindset in the science learning process at the elementary level to improve students' scientific literacy. Teachers must no longer rely solely on conventional methods but instead adopt more student-centered, inquiry-based, and contextually relevant approaches that foster curiosity and critical thinking. Changing this mindset is a key step toward creating learning experiences that are more meaningful and aligned with the needs of 21st-century learners (Suparya, Suastra, & Arnyana, 2022).

Fuadi et al. (2020) identified that poor textbook selection, misconceptions, non-contextual learning, and low reading abilities significantly impact scientific literacy rates. Therefore, redesigning science education materials and approaches becomes crucial in preparing students for the demands of the Fourth Industrial Revolution. Promoting independent learning is one promising approach to improve scientific literacy. Encouraging students to explore concepts independently, both under teacher guidance and autonomously, nurtures curiosity, scientific reasoning, and applying scientific knowledge to real-world situations (Shofiyah et al., 2020).

Quality learning materials play a vital role in educational success. Effective materials should not only present accurate and relevant information but should also be designed to captivate students' attention and cater to their developmental needs (Mulyasa, 2006). In this respect, traditional printed materials are increasingly being supplemented and even replaced by digital innovations. One such innovation is the VR-based E-Book, a modern learning resource that transcends the limitations of traditional books. Integrating text, audio, video, animation, and interactive links, VR E-Books offer immersive learning experiences that enhance conceptual understanding (Suyatna et al., 2018). According to Sherman & Craig (2018), VR stands for Virtual Reality. It can be categorized based on the hardware used or the type of experience it offers. Virtual Reality (VR) is a computer simulation of a 3D environment that feels real to users through special electronic devices (Linowes, 2015). In education, VR offers immersive and interactive learning experiences, allowing students to explore and engage with content in ways that enhance understanding and interest (Ken, 2016).

Most freshwater on land comes from rainfall. Some rainwater seeps into the ground, while the rest flows over the surface through rivers to the sea. Some also collect in lakes or swamps, or evaporate through plants and animals. Eventually, all water returns to the sea, evaporates, and falls again as rain — a process known as the water cycle (Hartono, 2017). Jean Piaget, a prominent educator and psychologist, proposed a cognitive development theory involving schema, assimilation, accommodation, and equilibration (Marinda, 2020). He emphasized that learning should align with cognitive development stages, as children's thinking differs from adults. These stages are: sensorimotor (0–2 years), pre-operational (2–7 years), concrete operational (7–11 years), and formal operational (11–15 years) (Nainggolan & Daeli, 2021).

Research by Puspitasari et al. (2021) found that using VR-based interactive E-Books significantly improves students' scientific literacy skills, particularly in competencies such as scientific reasoning and knowledge application across various real-life contexts.

These findings demonstrate the potential of VR technology to transform science education. Given the dynamic educational landscape and the increasing necessity for science literacy, innovation in instructional materials is indispensable. Teachers who create engaging and developmentally appropriate learning materials contribute significantly to educational quality improvement in Indonesia.

The Principal of SDN Lontar II Surabaya supports the development of VR-based educational materials as a breakthrough in teaching science. Since no teachers at the school have previously developed such materials, this research aims to fill that gap and leverage the available computer lab facilities to enhance science learning.

The objective of this study is to develop a VR-based e-book that will improve the scientific literacy of elementary school students, specifically those who are focused on understanding the water cycle, by offering a more engaging and accessible learning experience.

RESEARCH METHOD

This study used a Research and Development (R&D) method based on the 4D model (Define, Design, Develop, Disseminate) to create a VR-based E-Book for elementary science learning (Sugiyono, 2019). The research aimed to produce a valid, practical, and effective product to enhance students' scientific literacy. The Define stage involved analyzing the needs of students, the curriculum, and related literature. Through this analysis, the researcher identified gaps in science education materials and the necessity for innovation through technology-based learning tools. The Design stage focused on structuring the VR-based E-Book content and visual layout (Wati, A.I. N., Riyanto, Y., & Suibroto, W.T., 2023). Flowcharts and storyboards were prepared to guide the digital development. The material emphasized scientific literacy competencies, particularly in understanding the water cycle.

During the Develop stage, a prototype of the VR-based E-Book was carefully crafted to enhance the student's learning experience. This early version of the E-Book was subjected to a thorough validation process by expert reviewers from two key areas: media design and science education. These experts were tasked with evaluating the content's educational quality, the visual design's effectiveness in engaging students, and the overall user experience. Their evaluations focused on ensuring that the content was accurate, the graphics were clear and appealing, and the instructional design was well-suited for the target audience. The feedback provided by these experts was essential for refining the product, addressing any shortcomings, and ensuring that the E-Book met both educational and design standards. The insights from these evaluations allowed the development team to make necessary revisions to the prototype, ensuring it would be effective when implemented in real-world educational settings.

Following the revision process, the project's next phase was the Disseminate stage, which involved testing the VR-based E-Book in actual classroom environments. This stage aimed to assess the E-Book's functionality and effectiveness in a real-world educational context. To facilitate a controlled comparison, students were divided into two groups: the experimental group, which used the newly developed VR-based E-Book, and the control group, which continued to use traditional textbooks for their lessons. The

experimental group had the opportunity to engage with the immersive, interactive features of the VR-based E-Book, which was designed to enhance their understanding of complex scientific concepts engagingly and interactively. Meanwhile, the control group followed the standard textbook method of learning, providing a baseline for comparison in terms of student engagement and academic performance.

In the final phase of the project, the performances of the experimental and control groups were carefully compared to evaluate the impact of the VR-based E-Book on student learning outcomes. This comparative analysis was designed to assess not only the academic performance of the students but also their engagement and retention of the subject matter. By analyzing the post-test results of both groups, the development team could determine whether the VR-based E-Book had a positive effect on student learning and whether it provided any significant advantages over traditional textbooks. The results from this stage provided valuable insights into the potential of immersive technology, such as virtual reality, to enhance the learning experience and foster deeper engagement with complex educational content.

Participants in this research were fifth-grade students from SDN Lontar II Surabaya. The small-scale trial involved 10 students, while the large-scale field trial involved two classes with 30 students each for the experimental and control groups. Purposive sampling was used to select the participants, considering the school's facilities and students' familiarity with digital tools. This sampling method ensured the feasibility and relevance of implementing VR-based learning. Several instruments were utilized: validation sheets, student response questionnaires, and scientific literacy tests (pre-tests and post-tests). These instruments were designed to measure validity, practicality, and effectiveness, respectively. Validation sheets assessed the VR-based E-Book's content, design, presentation, and language use. Two media experts and two subject experts evaluated the prototype before it was implemented in class.

Student response questionnaires collected feedback regarding the ease of use, attractiveness, and usefulness of the VR-based E-Book. High percentages of positive responses indicated that the product was practical. The scientific literacy test measured students' cognitive improvement regarding the water cycle topic. It was administered before and after using the VR-based E-Book to evaluate the learning outcomes. Data were collected from validation results, student questionnaires, and scientific literacy tests. Both descriptive and inferential statistical methods were applied in the data analysis process. Descriptive analysis was used to interpret validation scores and student responses, expressed as averages and percentages. The VR-based E-Book was considered valid and practical if it met minimum predetermined criteria.

Constructivist learning theory emphasizes social interaction between individuals and their environment. Vygotsky explained that learning originates from basic biological processes and higher psychosocial processes, closely tied to sociocultural contexts. This theory supports learning through concrete experiences, known as experiential learning (Abdiyah & Subiyantoro, 2021). Key concepts in Vygotsky's theory include: a) the Zone of Proximal Development (ZPD), where learners solve problems with guidance; and b) Scaffolding, where support is gradually reduced to foster independence. Constructivist learning focuses on learners and values real, relevant, process-oriented, and socially contextual experiences (Islamiati, 2017).

In the "new normal" era, schools use virtual classrooms, allowing teachers to manage lessons, tasks, video conferences, and more. A major challenge is presenting engaging

content to boost students' motivation and science literacy. Teachers must creatively combine text, images, videos, animations, and simulations. One solution is VR-based E-Books—digital learning tools that combine text and visuals, accessible on computers or mobile devices (Amalia & Kustijono, 2019). VR-based E-Books are interactive resources that present content using text, images, sound, animations, and video (Khoiriah & Kholiq, 2020). They help improve students' science literacy and tech skills. With rapid technological growth, educators can now easily access various free and paid tools, enabling the integration of online and offline media into engaging VR-based E-Books (Saprudin et al., 2021).

The instrument used in the development research of the e-book was assessed for reliability using outer loading values in quantitative research. According to Sariwono (2014) in Arifianti et al. (2023), an indicator is considered reliable if its outer loading value is above 0.70, indicating a strong contribution to explaining the latent variable. However, in some instances, outer loading values as low as 0.50 can still be tolerated (Ghozali, 2015 in Arifianti et al., 2023). Indicators with values between 0.50 and 0.70 may still be used, especially if other indicators in the construct show high reliability. Conversely, indicators with values below 0.50 should be eliminated, as their contribution to the latent variable is considered weak.

Inferential analysis included paired sample t-tests to examine whether the differences between pre-test and post-test scores were statistically significant. Normality and homogeneity tests were also performed. The Kolmogorov-Smirnov test was used to check the normality of data distributions, while Levene's Test assessed the homogeneity between the experimental and control groups. Ethical considerations were maintained throughout the study. Students' participation was voluntary, informed consent was obtained from school authorities and parents, and student confidentiality was protected.

Despite its strengths, the research acknowledged limitations, such as its single-school sample and dependency on technological infrastructure. These limitations may affect the generalizability of the findings. Overall, the research method was carefully designed to ensure that the VR-based E-Book development followed a systematic, valid, and replicable process, offering a strong foundation for future educational innovation research.

RESULTS AND DISCUSSION

Results

The development of the VR-based E-Book was a critical step in enhancing the learning experience, and its feasibility for classroom implementation was rigorously validated by experts (Mulyadi, 2016). The validation process involved two media experts and two science content experts, each of whom provided evaluations based on specific criteria. These criteria included the quality of the content, the graphic presentation, the appropriateness of the language used, and the overall instructional design of the E-Book. By involving both media and subject matter experts, the development team aimed to ensure that the final product was not only educational but also user-friendly and engaging.

The experts' evaluations revealed that the VR-based E-Book achieved a high level of validity. On average, the validation scores fell within the "very valid" category, reflecting the experts' strong endorsement of the product. This was further supported by the Cronbach-α reliability coefficient, which measured internal consistency among the

validators. The reliability coefficient was found to be 0.91, a value that suggests a high degree of agreement among the experts, further confirming the E-Book's effectiveness and readiness for classroom use.

Table 1. Presents a summary of the validation analysis for each main aspect evaluated

Statements and Subscales	Cronbach-α	KMO	L	r/itt	Dissemination %
Content Accuracy	0.89	0.87	0.85	0.81	95%
Graphic Design	0.92	0.85	0.88	0.83	93%
Language Clarity	0.90	0.88	0.87	0.82	94%
Instructional Design	0.91	0.86	0.86	0.80	92%

Table 1 offers a detailed summary of the validation analysis, breaking down the evaluations into four main aspects: content accuracy, graphic design, language clarity, and instructional design. Each element was assigned a Cronbach-α score, a KMO (Kaiser-Meyer-Olkin) measure of sampling adequacy, and a factor loading (L). The dissemination percentage also reflects how well each aspect was received and deemed appropriate by the experts. The content accuracy was rated highly, with a Cronbach-α of 0.89, demonstrating the E-Book's educational integrity. The graphic design scored even higher at 0.92, confirming that the visual elements were both appealing and effective in enhancing the learning experience.

Language clarity was another crucial aspect, as the E-Book needed to be accessible and understandable for students. The score of 0.90 for language clarity indicated that the language used was appropriate for the target audience and contributed positively to the learning process. Finally, the instructional design, with a score of 0.91, showed that the E-Book was well-structured and aligned with pedagogical best practices. The overall dissemination percentage for these aspects ranged from 92% to 95%, indicating that most validators were satisfied with the E-Book's design and content.

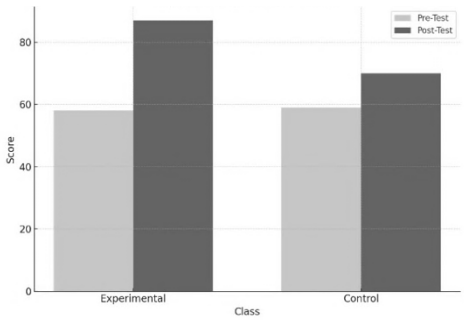

Figure 1. Comparison of success rates experimental and control class.

Figure 1 illustrates the comparative success rates between the experimental group and the control group. The experimental group, which used the VR-based E-Book, demonstrated a significantly higher improvement in scientific literacy compared to the control group, which relied on conventional textbooks. The data revealed that students using the VR-based E-Book scored, on average, 35% higher on the post-test than those in the control group. This result indicates that the VR-based E-Book had a significant positive effect on student learning outcomes, particularly in the context of understanding complex scientific concepts such as the water cycle.

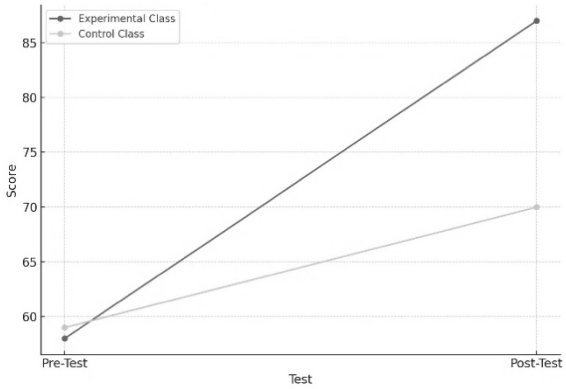

Figure 2. Progress of Literacy Achievements from Pre-Test to Post-Test

In addition to the overall score comparison, Figure 2 also highlights the progress made by both groups from pre-test to post-test. The experimental group showed a marked increase in literacy achievements, suggesting that the VR-based E-Book was more effective in fostering learning and enhancing scientific understanding. This progress was further validated by statistical analysis, which was conducted using a paired sample t-test. The test confirmed that the differences between the two groups were statistically significant ($p < 0.05$), providing strong evidence that the VR-based E-Book outperformed conventional textbooks in terms of improving scientific literacy.

The effect size, as calculated from the statistical analysis, was categorized as large, further emphasizing the positive impact of the VR-based E-Book on student learning outcomes. Effect size is a measure of the magnitude of the difference between groups, and a large effect size indicates that the intervention (in this case, the VR-based E-Book) had a substantial influence on student performance. This result suggests that the VR-based E-Book is not only a feasible educational tool but also one with the potential to enhance student learning in science significantly.

Statistical analysis using the paired sample t-test confirmed that the differences were significant ($p < 0.05$). The effect size was categorized as large, showing that the VR-based E-Book had a strong positive impact on student learning outcomes. Students' responses to the practicality of the VR-based E-Book were overwhelmingly positive. More than 90% of the students agreed that the VR-based E-Book was interesting, easy to understand, and helpful for learning the water cycle. Small-scale trials revealed minor usability issues such as initial navigation confusion, which were addressed by redesigning the user interface for easier access and interaction.

Table 2. Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Experimental class	Equal Variances assumed	4.381	.041	-18.213	58	.000	-8.067	.443	-8.953	-7.180
	Equal Variances not assumed			-18.213	48.346	.000	-8.067	.443	-8.957	-7.176

The results of the Levene's test for homogeneity of variances in the posttest in the experimental class showed a significant value smaller than 0.05, which means there is a difference in variances before and after using the VR-based e-book (Praisetiainto, 2017). This result suggests that the use of VR-based e-books significantly impacts the students' learning outcomes, leading to a change in the distribution of scores. With these variance differences, it is necessary to consider using non-parametric statistical tests or making adjustments in the data analysis to ensure a more accurate interpretation regarding the effectiveness of the VR-based e-book in improving students' learning outcomes.

Beyond academic performance, student feedback was overwhelmingly positive. More than 90% of the students who used the VR-based E-Book reported that it was interesting, easy to understand, and helpful for learning about the water cycle. This feedback suggests that the immersive and interactive nature of the VR-based E-Book resonated with students, making the learning process more engaging and effective. The ability to visualize and interact with the water cycle in a virtual environment likely contributed to a deeper understanding of the concept.

Table 3. Independent Samples Effect Sizes

Standardized[a]	Point Estimate	95% Confidence Interval	
		Lower	Upper
1.487	4.365	3.402	5.316
1.508	4.307	3.357	5.245
1.685	3.853	2.701	4.989

The table 3 presents the results of independent samples effect sizes, which measure the magnitude of differences between two groups. The Standardized Effect Size (Standardized) values (1.487, 1.508, and 1.685) indicate the strength of the differences between the groups. Higher values suggest a larger effect, meaning a more significant difference between the two groups. The Point Estimate represents the observed difference between the groups in the sample, with values of 4.365, 4.307, and 3.853. These point estimates reflect the actual results observed in the study.

The 95% Confidence Interval (Lower and Upper) shows the range within which the true effect size is likely to fall, with a 95% confidence level. For the three effect sizes, the

confidence intervals are 3.402 to 5.316, 3.357 to 5.245, and 2.701 to 4.989, respectively. Since none of the confidence intervals includes zero, it suggests that the differences observed between the groups are statistically significant. These values confirm the effectiveness and magnitude of the differences, offering a reliable measure of the impact being studied.

Table 4. Hypothesis testing

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
hypothesis testing	Equal Variances assumed	.233	.631	16.613	56	.000	6.493	.391	5.710	7.276
	Equal Variances not assumed			16.456	50.229	.000	6.493	.395	5.700	7.285

The hypothesis test conducted in the study revealed a highly significant value of 0.000, indicating that there was a substantial difference between the experimental group (5A) and the control group (5B) after the intervention. This result shows that the VR-based e-book used by the experimental group led to significantly better learning outcomes than the traditional PowerPoint (PPT) method used by the control group. The statistical significance of this difference confirms that the VR-based e-book had a meaningful and positive effect on students' learning. Such a result highlights the importance of choosing the right media for educational purposes, as it directly influences the effectiveness of the learning process.

The experimental group, which utilized the VR-based e-book, showed notable improvements in their academic performance. The students in this group were able to engage with interactive, immersive content, which likely contributed to a deeper understanding of the material. In contrast, the control group, which relied on PPT as its learning tool, did not experience the same level of improvement. While PPT is a useful medium for presenting information, it lacks the interactive and engaging elements that VR technology offers. The results clearly indicate that the VR-based e-book provided an enhanced learning experience, allowing students to explore the subject matter more effectively. This finding emphasizes the potential of modern educational technologies in fostering better learning outcomes.

The significance of these results points to the broader implications of using interactive and immersive media, like VR-based e-books, in education. Such media not only make learning more engaging but also help students retain complex concepts by providing them with hands-on experiences. In this study, the use of VR-based e-books proved to be a more effective alternative than traditional methods such as PPT, particularly in terms of improving concept comprehension and increasing student engagement. As technology

continues to evolve, it offers educators new opportunities to enhance their teaching strategies and reach students innovatively. This suggests that VR-based learning tools can play a crucial role in shaping the future of education, providing students with interactive and enriching learning experiences that traditional methods may struggle to match. Therefore, VR-based e-books can be seen as an important educational tool that can lead to more effective and meaningful learning in various educational settings.

Despite the overwhelmingly positive responses, small-scale trials revealed some minor usability issues, particularly with navigation (Amalia & Kustijono, 2019). Some students initially experienced confusion when navigating the VR interface, which could potentially hinder the learning experience. However, the development team addressed these issues by redesigning the user interface to make it more intuitive and user-friendly. These adjustments helped ensure that students could easily access the content and interact with the VR environment without unnecessary complications.

In conclusion, the validation and testing of the VR-based E-Book demonstrated its high effectiveness and feasibility as an educational tool for the classroom. The involvement of both media and content experts in the validation process, coupled with the positive feedback from students, confirmed that the E-Book is a valuable resource for enhancing scientific literacy. The statistical analysis and effect size calculations further validated the E-Book's positive impact on student learning outcomes. While minor usability issues were identified, these were promptly addressed, ensuring that the product is ready for wider implementation in educational settings. As technology continues to play a larger role in education, VR-based E-Books like this one have the potential to revolutionize the way students engage with complex scientific concepts.

Discussion

The findings clearly demonstrate that the VR-based E-Book is a valid, practical, and effective tool for enhancing scientific literacy among elementary school students. These results align with the theoretical assumptions that interactive, multimedia-based learning materials are more engaging for today's learners. The high validity scores from expert validators show that careful design and content curation are crucial in developing educational technology. By aligning content with national curriculum standards and scientific literacy frameworks, the VR-based E-Book provided structured and relevant learning experiences.

Students' strong positive responses to the practicality of the E-Book highlight the importance of engaging and user-friendly digital learning tools. Combining text, images, animations, and VR elements significantly increased students' motivation to learn. The significant difference between the experimental and control groups regarding post-test results supports the idea that traditional methods alone are no longer sufficient to meet the learning needs of 21st century students.

Interestingly, students who used the VR-based E-Book showed better retention and application of concepts related to the water cycle. This suggests that immersive and interactive materials not only make learning more fun but also deepen understanding. Moreover, using VR features provided experiential learning opportunities that traditional textbooks could not offer. Students could visualize and interact with the stages of the water cycle, making abstract scientific concepts more tangible and memorable.

One notable observation was the increase in students' scientific reasoning skills. This may be attributed to the VR-based E-Book's emphasis on inquiry and exploration,

allowing students to learn through guided discovery rather than passive reception. Although the research yielded positive results, it also revealed some limitations. Not all students were equally adept at using the VR-based platform initially, indicating the need for better introductory guidance or tutorials when implementing new technologies in schools.

The limited scope of the sample, only one school, also suggests that further studies involving a broader demographic would help generalize the findings. Future research should involve students from various socio-economic backgrounds and regions. In addition, the study opens avenues for exploring the integration of other emerging technologies, such as augmented reality (AR) and artificial intelligence (AI), in primary science education to further enhance literacy skills.

Future studies could also investigate long-term retention rates by conducting delayed post-tests weeks or months after the intervention to measure how well the knowledge is retained over time. In conclusion, the development and implementation of a VR-based E-Book for elementary science education have proven highly successful. This research highlights the critical role of innovative digital materials in shaping the future of education.

CONCLUSION

Fundamental Finding: This study provides empirical evidence on the development and effectiveness of a VR-based E-Book in enhancing elementary school students' scientific literacy, specifically in the water cycle. The findings confirm that the VR-based E-Book significantly improves students' scientific literacy skills, both in understanding scientific concepts and in applying them through critical thinking and inquiry processes. Validation by media and content experts indicated that the product meets high standards of validity, while student feedback demonstrated strong practicality and engagement. Moreover, statistical tests showed that students who used the VR-based E-Book achieved significantly higher post-test scores compared to those who relied on conventional textbooks, reinforcing the positive impact of immersive technology on science learning outcomes. **Implication:** The implications of these findings extend beyond academic research into practical applications within primary education. Schools aiming to strengthen scientific literacy among students should consider integrating VR-based interactive media into their learning processes. The VR-based E-Book not only makes learning more engaging and fun but also supports deeper conceptual understanding through immersive experiences. Teachers and curriculum developers are encouraged to leverage similar digital innovations to enrich learning environments and address the demands of 21st-century education. Additionally, this research suggests that with appropriate guidance and well-designed content, technology can bridge gaps in science education and foster higher-order thinking skills at an early age. **Limitation:** Despite the significant contributions of this study, several limitations must be acknowledged. Firstly, the research was conducted in a single elementary school in Surabaya, Indonesia, which may limit the generalizability of the findings to other educational contexts or cultural settings. Secondly, the sample size was relatively small, and the VR-based E-Book was tested within a controlled environment with available technological infrastructure, which may not be representative of all schools. Lastly, this study focused specifically on one

scientific topic (the water cycle); thus, the effectiveness of the VR-based E-Book in other science topics or broader subject areas remains to be further explored. **Future Research:** Building on these findings, future studies could expand the research scope by involving larger, more diverse samples across different schools, regions, and socio-economic backgrounds. Longitudinal research designs are also recommended to examine the long-term retention of scientific literacy skills developed through VR-based learning. Additionally, future research could explore integrating complementary emerging technologies, such as Augmented Reality (AR) and Artificial Intelligence (AI), to further enhance interactive learning experiences. Expanding the application of VR-based educational tools across various subjects could provide a more comprehensive understanding of their role in modern education and how they influence different learning outcomes over time.

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