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Physics Learning Utilizing VIRRIC (Virtual Reality Hydroelectric): Effects on Students' Learning Outcomes and Experiences

Aminudin Zakaria[1], Mita Anggaryani[1*], Tinezia Cendani[1], Nina Fajriah Citra[2]

[1]Universitas Negeri Surabaya, Surabaya, Indonesia
[2]Monash University, Melbourne, Australia

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ABSTRACT

Objective: *This study explores the impact of physics learning using VR-based media on students' learning outcomes and learning experiences. This study also examined gender differences in gains.* ***Method:*** *This study uses the one-group pre-test and post-test methods to measure learning outcomes and a questionnaire to determine student responses. These student responses assess how students experience learning after using the Virtual Reality Hydroelectric (VIRRIC) media. This paper reports on the design, implementation, and impact of applying VIRRIC. VIRRIC was created using MilleaLab Creator software, a VR platform inspired by the Karangkates Hydroelectric Power Plant. The inspiration for this real renewable energy product is to support students in contributing to SDG 7. VIRRIC was tested in science class learning, and 30 high school students were tested.* ***Results:*** *The trial results showed that 93% of students had a moderate n-gain (average n-gain = 0.433), indicating a decent increase in learning outcomes before and after using VIRRIC. In addition, the application of VIRRIC was well received by the students, with a questionnaire score of 0.76, indicating that they had good learning experiences in physics through VIRRIC. Both results show a positive correlation between STEM activities using VIRRIC and students' learning outcomes and learning experiences. Therefore, VIRRIC can be a medium for teaching, particularly on the renewable energy topic.* ***Novelty:*** *This study provides scientific evidence of VR technology's effectiveness in supporting physics learning. It provides empirical evidence of how conventional physics learning can be transformed into digitalization using VR.*

INTRODUCTION

Virtual reality (VR) technology is significantly correlated with the digital transformation of education, both now and in the future (Yie et al., 2023). The goal of nurturing a well-being-oriented generation is to prepare individuals to face diverse future challenges, a vision often referred to as building a sustainable society. Achieving this vision requires the active concern and support of various stakeholders within the education system. The United Nations has established Sustainable Development Goals (SDGs), which are targeted for achievement by 2030. Among these, Sustainable Development Goal (SDG) 7 aims to ensure universal access to affordable, reliable, modern, and sustainable energy, benefiting both society and the environment (Güney, 2019; Mulugetta et al., 2019). One practical approach to achieving this goal is integrating the Science, Technology, Engineering, and Mathematics (STEM) framework into the learning process (Fathurohman et al., 2023; Gamage et al., 2022; Ong et al., 2023). Integration of STEM in physics, especially by understanding how renewable energy systems work and applying engineering design principles, can support achieving SDG 7. (Dossymov et al., 2026; Liston, 2024).

STEM learning emphasizes students' ability to integrate knowledge across disciplines. This interdisciplinary approach enables students to develop the skills necessary for solving real-world problems (Hobbs et al., 2018; Holmlund et al., 2018; Newhouse, 2016; Promboon et al., 2018). These competencies can be nurtured through the four interconnected STEM components (Lai et al., 2019). Students are encouraged to solve complex problems by integrating concepts from science, engineering, technology, and mathematics, thereby fostering higher-order thinking (Permanasari et al., 2024). The benefits of STEM learning underscore its importance in education, particularly due to its positive impact on students' academic outcomes (Awad, 2021; Kelley et al., 2020). STEM-based instruction can be implemented through various strategies, including integrating environmental issues and efforts to address them (Turner et al., 2022).

Environmental issues addressed by SDG 7 include the continued reliance on fossil fuels as a primary energy source. Electricity generation is the largest consumer of fossil fuels, accounting for approximately 60% of global consumption (Ritchie & Rosado, 2017). According to the International Energy Agency (IEA), coal remains the dominant source of electricity, with total consumption reaching 8 billion tons in 2022. The combustion of coal produces hazardous and toxic pollutants (Qolbi et al., 2023).

Transition to renewable energy sources is essential to mitigating the environmental damage caused by fossil fuels. Renewable energy refers to any form of energy derived from natural resources that replenish faster than they are consumed (Dale et al., 2016). Sources such as sunlight, wind, water, tides, geothermal heat, and biomass fall into this category (Alrikabi, 2014; Ang et al., 2022; Owusu & Asumadu-Sarkodie, 2016). Among these, hydropower, which generates electricity from flowing water, is the most widely utilized renewable energy source (Ang et al., 2022; Dale et al., 2016). Its relevance to education for sustainable development is evident in its potential to contribute to the Human Development Index (HDI), particularly through improved access to electricity.

Recent studies emphasize the crucial role of electricity access in improving educational outcomes within the HDI framework (Mulugetta et al., 2019). Hydropower technology, closely linked to science, engineering, and mathematics, provides an effective context for STEM learning (Honey et al., 2014). However, students often show low motivation in physics learning, a problem frequently attributed to the lack of engaging teaching methods and media (Musyarrof et al., 2018). Educators also face constraints, such as limited time and resources, that hinder effective physics instruction (Suhartini, 2023). One promising solution to address this issue is the utilization of ICT tools, particularly virtual reality (VR), which has been proposed to offer immersive, metaverse-based learning experiences (Brahma et al., 2023; Elvira & May, 2019; Núñez et al., 2022).

Various ICT technologies have been developed to enhance learning experiences by incorporating metaverse elements. One notable application is the use of virtual laboratories, which have demonstrated their ability to increase student motivation. However, most studies have focused on virtual labs in physics, chemistry, and biology, with a strong emphasis on learning motivation alone (Karimova et al., 2025). There is a noticeable gap in exploring other learning variables, such as students' overall experiences and learning outcomes.

In addition, the use of VR in physics education has grown significantly over the past two decades (Citra & Anggaryani, 2022). While several studies have explored VR-based laboratories, they typically rely on desktop systems that do not fully exploit VR's immersive potential (Rasheed et al., 2021). Furthermore, assessments in these studies often rely solely on quizzes to measure learning outcomes, without investigating students' deeper learning experiences.

A previous study reported that using Gravity Sketch software for VR-based physics learning had a mobility disadvantage. The software required a desktop PC and could not be used by all students (Campos et al., 2022). However, the study found that VR can significantly assist and facilitate the visualization of abstract physics concepts. Therefore, a more flexible, interactive, and mobile VR solution is needed, making it better suited for classroom implementation.

Other previous studies have also reported the benefits of VR for enhancing conceptual understanding and student engagement. For example, Fauziah et al. (2024) reported that VR-assisted visualizations support both theoretical and practical understanding. Similar results were reported by Kartikasari & Anggaryani (2022) and Prillyanti & Anggaryani (2023), who found that conceptual mastery and learning experiences can be enhanced through VR-assisted learning. These findings are also corroborated by Agusty (2021) and Devianti (2022), who emphasized that VR plays a crucial role in promoting interactive learning and improving student performance. Collectively, the findings from these previous studies point to VR's significant potential to advance physics learning and contribute to achieving the SDGs.

The research results mentioned above have disadvantages in VR usage. Access to VR requires a VR headset, which limits accessibility. Furthermore, overly complex VR content can hinder the effective delivery of the message. This study attempts to address this by designing concise VR content. This content can be easily accessed on a smartphone with a low-cost VR Cardboard in physics learning (Zakaria & Anggaryani, 2024b).

Physics learning can be effectively implemented by presenting local contexts in both urban and rural schools (Boda & Brown, 2020). Everyday phenomena frequently observed by students can be an important and meaningful starting point to support a stronger understanding of concepts (Permanasari et al., 2024). Real-world experiences and problems offer students opportunities to engage in scientific inquiry and problem-solving actively (Roehrig et al., 2021). It is crucial to link physics learning development to issues aligned with the Sustainable Development Goals (SDGs). Through SDG-related issues, students can raise awareness of global challenges (Wahyuni et al., 2024). To support this learning, VR can simulate real-world scenarios, thereby enhancing the learning experience through an immersive, accessible environment.

In response to this need, researchers have developed a VR-based physics learning tool, Virtual Reality Hydroelectric (VIRRIC) (Zakaria & Anggaryani, 2024a). VIRRIC was first developed in 2024 as early-stage research before being implemented in this study.

VIRRIC has undergone validation and limited trials, yielding suitable results for use in physics classes. However, a larger investigation is still needed to determine how VIRRIC affects students' learning outcomes and learning experiences in a real classroom context. Through VIRRIC-assisted physics learning activities, it is hoped that students' understanding of physics concepts will increase. At the same time, they develop digital competencies crucial to addressing the 21st-century global challenges (Permanasari et al., 2024). Therefore, this study aims to investigate the implementation of VIRRIC and its effects on student learning outcomes. This research was conducted in a physics learning context that supports SDG 7 on affordable and clean energy.

RESEARCH METHOD

This study employed a modified one-group pre-test post-test design, adapted from the traditional quasi-experimental model (Rogers & Revesz, 2020; Sugiyono, 2019). The design was enhanced by integrating qualitative evaluation components to gain deeper insights into students' understanding and engagement during the virtual reality (VR)-based learning process.

A total of 30 students from a public senior high school in Jombang, East Java, Indonesia, participated in the study. Of these participants, 8 were male, and 22 were female, with ages ranging from 14 to 16 years at the time of the research. All students were part of the same class group, which ensured a consistent and comparable initial learning environment across the sample. This selection was based on the uniformity of academic characteristics and the ease of access for researchers to conduct in-depth observations. Given the exploratory nature of this research, a relatively small sample size was still considered adequate to identify initial patterns.

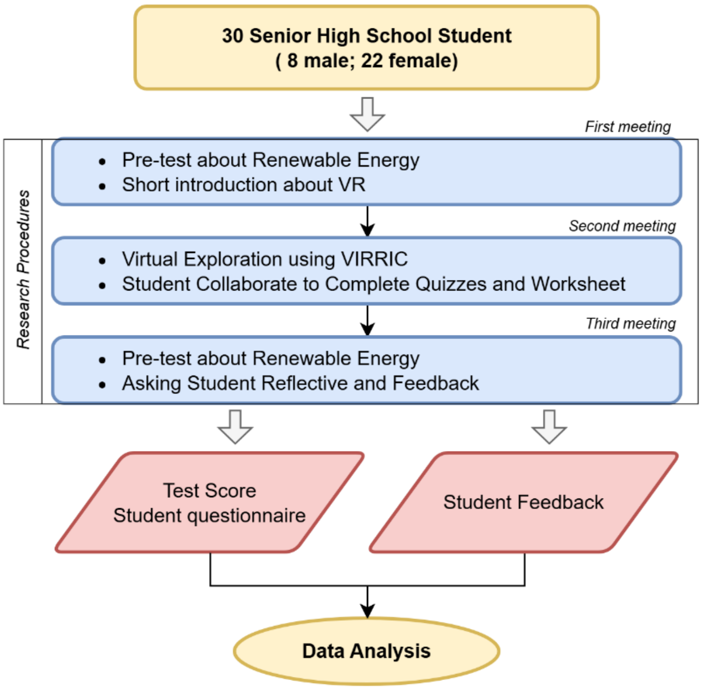

Figure 2. Research procedures diagram

The sampling technique used in this study was purposive sampling, guided by specific inclusion criteria. Participants were selected based on two conditions: (1) they had completed instruction on the sub-topic of renewable energy as part of the physics curriculum, and (2) they had no prior experience using virtual reality (VR) in an educational context.

This research was conducted over three class sessions. In the first session, a pre-test was administered to measure students' initial understanding of renewable energy concepts. The pre-test consisted of 20 multiple-choice questions. These questions were designed to measure students' understanding of the fundamentals of renewable energy and their ability to apply this knowledge at the cognitive levels of Bloom's Taxonomy. The test instrument was structured around competency indicators in the Independent Curriculum, including conceptual understanding, analysis, and the application of knowledge. Furthermore, in this session, students were divided into small groups of three to four, and each group received a VR cardboard kit to introduce them to VR technology in learning.

In the second session, students began a virtual exploration of a hydroelectric power plant (PLTA) using the VIRRIC platform. Student worksheets and teacher instructions guided this exploration. While exploring the virtual environment, students were required to complete quizzes embedded in the VIRRIC system and collaborate on tasks on their group worksheets. After participating in the VR exploration activity, students were asked open-ended qualitative questions to describe their VR experiences.

$$g_{ave} = \frac{post - pre}{100 - pre} \quad (1)$$

In the final meeting, students completed the post-test to assess their learning outcomes. Student learning outcomes analyzed through the normalized gain (n-gain) method proposed by Hake (1998), as shown in Equation 1. The gain scores were interpreted using classification criteria presented in Table 1. To facilitate data analysis and address the research questions, descriptive statistics and effect size calculations were also employed.

Table 1. Interpretation of n-gain test (Hake, 1998)

g_{ave} Value	Gain Criteria
$g_{ave} > 0.70$	High
$0.30 \le g_{ave} \le 0.70$	Moderate
$g_{ave} < 0.30$	Low

Table 2. Categories of Cohen's d effect size (Brydges, 2019)

Cohen's d value	Criteria
0.2	Small
0.5	Medium
0.6	High

In the third meeting, students were also asked to provide feedback on their experiences during the learning activities facilitated by VIRRIC. Students' perceptions of the VR-based learning experience were assessed using a 4-point Likert scale questionnaire, adapted from (Mulyatiningsih, 2012). To analyze the collected data, descriptive statistical methods were employed. The percentage of responses for each item was calculated using Equation 2.

$$P(\%) = \frac{\Sigma x}{\Sigma x_{ideal}} \times 100\% \quad (2)$$

Table 3. Student response interpretation (Arikunto, 2018)

Scale	Responses
80% - 100%	Very Good
66% - 79%	Good
40% - 65%	Bad
<39%	Very Bad

To gain deeper insights into students' learning experiences, this study incorporated semi-structured interviews with a purposively selected subset of five students based on their variation in test performance. The interviews explored students' conceptual understanding, the perceived benefits of VR-based instruction, and the challenges they encountered. Thematic coding was used to analyze the interview transcripts (Braun & Clarke, 2008).

Additionally, to explore potential differences in how students interact with VR in science learning, a gender-based comparative analysis was conducted. Learning gains between male and female students were compared using descriptive statistics. While the small sample size limits generalizability, this preliminary comparison offers valuable insights for future research on inclusivity in VR-enhanced physics education.

RESULTS AND DISCUSSION

Results

Observations conducted during the initial meeting revealed that students had not yet developed a clear understanding of renewable energy, particularly in relation to STEM and the Sustainable Development Goals (SDGs). Students reported that their knowledge was primarily derived from textbooks, static images, and teacher explanations. In the context of electricity generation, they were only familiar with various types of power plants, without understanding how clean, renewable electricity is produced. Although students appeared to grasp the concept of renewable energy, it left little lasting impression, resulting in rapid forgetting. This was reflected in the pre-test scores, with an average of 55.17 out of 100, a minimum score of 30, and a maximum of 75. The descriptive statistical results for the pre-test and post-test are shown in Table 4.

Table 4. Descriptive Statistics Result

	PRE	POST
N	30	30
Mean	55.2	75.0
Median	55.0	75.0
Standard deviation	12.5	8.20
Minimum	30	60
Maximum	75	90

Figure 1. karangkates hydroelectric power plant and visualization in VR

These findings indicate that conventional teaching approaches have not been effective in facilitating deep and sustained information retention in students' long-term memory. According to Kelley & Whatson (2013), information delivered in massed formats, without optimal timing patterns and diverse stimuli, tends to remain only in short-term memory and is easily forgotten. Similarly, Cotton & Ricker (2022) emphasize that memory consolidation—whether in working memory or long-term memory—requires adequate time and cognitive engagement to stabilize memory traces against interference. Therefore, appropriate stimulation is essential in the learning process, such as through interactive educational media like virtual reality (VR), to enhance the encoding and consolidation of information into more stable, meaningful long-term memory.

The implementation of Virtual Reality (VR) technology was well-received, with students showing strong enthusiasm and rapid proficiency in installing VIRRIC and assembling VR Cardboard kits. Minor challenges, such as limited internet connectivity and iOS compatibility issues (less common in Indonesia), were quickly resolved by the students themselves. This adaptability aligns with their status as Generation Z digital natives (Szymkowiak et al., 2021), whose innate technological familiarity facilitated seamless VR adoption.

At the commencement of physics lessons, students engage with VIRRIC media as a primary learning tool. The instructional process adopts a problem-based learning model centered on electrical energy concepts. Working collaboratively in groups, students utilize VR Cardboard Headsets to access VIRRIC's fully immersive environment while referring to structured worksheets for task guidance. During this phase, instructors facilitate student exploration of the virtual environment, which features a functional hydroelectric power plant simulation, and provide explanatory support regarding its operational mechanisms.

The hydroelectric power plant module within VIRRIC is modeled after the Karangkates Dam hydroelectric facility in Malang Regency, Indonesia – a plant with an annual generation capacity of 400 kWh (Sunaryo & Susilo, 2017). As depicted in Figure 2, the actual Karangkates facility obscures critical components from view: the water conduits are enclosed, while the turbines and generators remain housed within the powerhouse. To enhance pedagogical effectiveness, the virtual model incorporates strategic simplifications, rendering these essential components observable as shown in Figure 2. This adaptation maintains technical accuracy while optimizing the learning experience by deliberately visualizing energy conversion processes.

Table 5. Student responses to learning experiences using VIRRIC

No.	Aspect	Statement	Score	Category
1.	Display	VIRRIC stimulates my curiosity	0.77	Good
2.		VIRRIC increases my motivation to learn physics	0.76	Good
3.		VIRRIC is engaging and enjoyable to use	0.84	Very Good
4.	Language	The diction in VIRRIC is easy to understand	0.74	Good
5.		The language used is clear and communicative	0.79	Good
6.		The sentences are concise and straightforward	0.77	Good
7.	Audio Visual	The illustrations are easy to observe clearly	0.78	Good
8.		Images and sounds are placed appropriately	0.81	Very Good
9.		The illustrations help me understand the material	0.80	Very Good
10.		The audio does not distract from the learning process	0.75	Good
11.	Functional	VIRRIC is easy to operate.	0.73	Good
12.		VIRRIC is comfortable to use	0.77	Good
13.		VIRRIC can be used independently	0.67	Good
14.		No adverse effects during use.	0.72	Good
15.		No adverse effects after use	0.76	Good
		Mean	**0.76**	**Good**
		SD	**0.04**	

Students demonstrated high enthusiasm during VR-based learning activities. They actively collaborated with their group members to complete the assigned student worksheet. The role of technology, specifically VR, was to facilitate collaboration rather than replace social interaction during the learning process (Bandono et al., 2023). By sharing VR devices within their groups, students engaged in discussions, exchanged ideas, and leveraged collective knowledge to solve problems (Wang et al., 2020).

Despite its benefits, implementing VR-based learning presented several technical challenges, including disassembled VR cardboard kits, soiled lenses, and dizziness reported by some participants. Nonetheless, all planned learning activities were completed. Post-session, students provided feedback on their experiences with the VIRRIC system, and the collected data are summarized in Table 5.

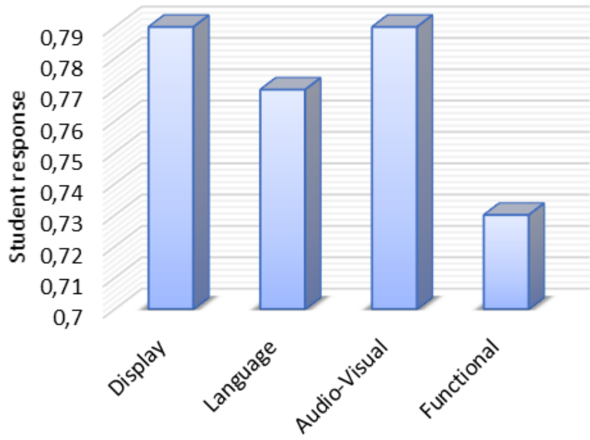

Figure 2. Summary of student responses

As illustrated in Figure 2, the display and audio-visual aspects received the highest scores, indicating a strongly positive student response. Meanwhile, the language aspect was also rated favorably, though slightly lower than the former two dimensions.

The positive reception of all three aspects is further supported by qualitative feedback from students.

"*The animations are well-designed, resembling cartoons while maintaining realism, and the background music creates an immersive atmosphere, as if being near a waterfall.*" (Student 1)

Another student also noted,

"*There are prompts for each object, and the information provided aids in understanding renewable energy concepts and completing the student worksheet.*" (Student 2)

These remarks reinforce the quantitative findings, demonstrating both engagement and perceived utility of the learning tool.

Meanwhile, the functional aspect received the lowest score. Although it still fell within the category of a positive response, several factors contributed to this lower rating. These issues were primarily related to challenges encountered by students during both the installation and use of VIRRIC, as previously outlined in the preceding paragraph. Some students provided comments regarding this aspect:

"I experienced slight dizziness while using VIRRIC." (Student 3)

Another student remarked:

"VIRRIC became uncomfortable after prolonged use." (Student 4)

Upon further clarification, it was confirmed that Students 3 and 4 had myopia (nearsightedness) and relied on corrective glasses for daily visual assistance. Consequently, this finding presents a critical point warranting further in-depth analysis.

During the final instructional session, students completed a post-test designed to measure learning outcomes following VIRRIC implementation. This assessment instrument served to evaluate knowledge acquisition and instructional effectiveness. Comparative results between pre-test and post-test scores are presented in Table 6.

Table 6. Summary of student pre-test and post-test scores

Group		M	SD	Min	Max
Male	Pre	47.50	10.35	45	65
	Post	71.25	7.44	60	80
	N-Gain	0.45	0.09	0.27	0.56
Female	Pre	57.95	12.21	30	75
	Post	76.36	8.19	60	90
	N-Gain	0.44	0.11	0.17	0.63
All	Pre	55.17	12.49	30	75
	Post	75	8.2	60	90
	N-Gain	0.44	0.11	0.17	0.63

The descriptive statistics reveal consistent learning improvements across gender groups. Male students demonstrated significant pre-to-post test score increases ($M_{pre} = 47.50,\ SD = 10.35$; $M_{post} = 71.25,\ SD = 7.44$), achieving a medium normalized gain ($n_{gain} = 0.45,\ SD = 0.09$). Female students showed comparable improvement ($M_{pre} = 57.95,\ SD = 12.21$; $M_{post} = 76.36,\ SD = 8.19$) with nearly identical N-gain scores ($0.44,\ SD = 0.11$). While female students exhibited greater score dispersion (range: 30-75 pre-test, 60-90 post-test) compared to males (45-65 pre-test, 60-80 post-test). This uniform progression pattern is visually supported by Figure 3.

The histogram displays the distribution of normalized gain (N-gain) scores for male students, female students, and the combined cohort. The majority of scores fall within the range of 0.35 to 0.55, indicating moderate learning gains across all groups (Hake, 1998). Male students exhibit a peaked and symmetric distribution centered around the mean ($M = 0.45, SD = 0.09$), suggesting consistent intervention effectiveness. In contrast, female students demonstrate a broader distribution ($M = 0.44, SD = 0.11$), reflecting greater variability in learning outcomes.

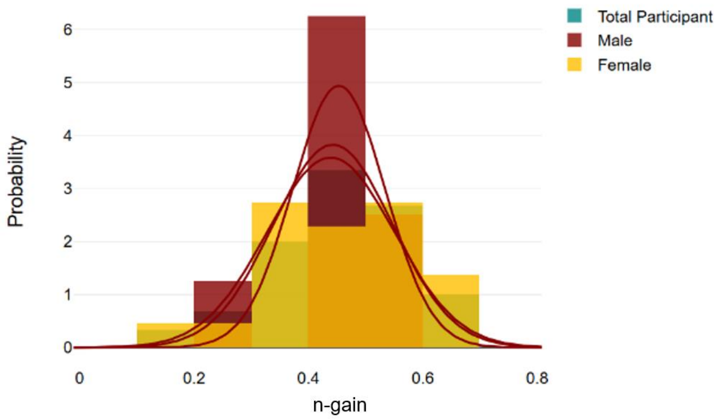

Figure 3. Distribution of n-gain scores by gender

Despite these distributional differences, both genders contribute equally to the overall balanced improvement trend, as evidenced by the nearly identical aggregate N-gain ($Total: M = 0.44, SD = 0.11$). This visual pattern confirms that VIRRIC intervention efficacy is moderate and comparable across genders, albeit with marginally higher consistency among male students.

To quantitatively compare intervention effectiveness, Table 7 presents effect size calculations (Cohen's d) for each subgroup, addressing whether observed variations are statistically or practically significant.

Table 7. Effect size (*Cohen's d*) based on n-gain

Group	N	Mean	SD
Male	8	0.45	0.09
Female	22	0.44	0.11
		Cohen's d	**0.13**

The effect size analysis indicates minimal differences in learning outcomes between gender groups ($Male$: $M = 0.45$, $SD = 0.09, n = 8$; $Female$: $M = 0.44$, $SD = 0.11, n = 22$), with a negligible Cohen's d effect size ($d = 0.13$). This statistically insignificant divergence ($d < 0.20$; Brydges, 2019) is consistent with the overlapping distribution patterns visible in the histogram (Figure 4). Consequently, these results suggest that gender does not significantly influence VIRRIC's instructional effectiveness.

Discussion

This study examined the impact of STEM activities using VIRRIC (Virtual Reality Hydroelectric) on students' learning outcomes and experiences. The results showed that students who engaged in physics lessons with VIRRIC demonstrated improved understanding of renewable energy concepts and had positive learning experiences. These findings are consistent with and extend previous research on the educational benefits of immersive technologies. (Asad et al., 2021; Yavoruk, 2024).

The analysis of quantitative data revealed a statistically significant improvement in student test scores, demonstrating that implementing VIRRIC effectively enhances understanding of renewable energy concepts, particularly hydroelectric power. This finding aligns with previous studies on the effectiveness of virtual reality in enhancing students' comprehension of complex scientific phenomena (Jensen & Konradsen, 2017; Radianti et al., 2020). However, VIRRIC offers a novel contribution by providing an immersive, interactive simulation of a hydroelectric power plant, enabling students to visualize the transformation of water flow into electricity and the dynamics of turbines—experiences that traditional VR platforms or conventional teaching methods often cannot provide. This unique approach further strengthens the case for VR's potential in STEM education by offering a more dynamic, tangible learning experience.

Furthermore, integrating VIRRIC into the STEM-based learning framework provides students with opportunities to explore real-world scientific applications through engineering design and critical thinking. This approach aligns with the fundamental principles of STEM education, which emphasize problem solving, discovery, and interdisciplinary learning (Bybee, 2013). In this study, students were not only passive recipients of information but also actively participated in simulation-based exploration, which contributed to a deeper conceptual understanding and retention of the topics.

Qualitative feedback and student reflections further supported the quantitative findings. The majority of students expressed enthusiasm and motivation during learning activities assisted by VIRRIC. A higher sense of presence and interactivity was reported, which helped keep focus and interest throughout the learning process. These results are supported by the study by Makransky et al. (2019), which highlighted the motivational and emotional advantages of immersive learning environments.

Additionally, the positive responses indicated that the VR environment not only enhanced cognitive aspects but also affected affective engagement. Students noted that a realistic visualization of a hydropower plant increased their awareness of renewable energy technologies and the importance of sustainability. These results are particularly significant when linked to Sustainable Development Goal (SDG) 7, which aims to ensure access to affordable, reliable, sustainable, and modern energy.

This study aims to contribute to the growing body of evidence on the effectiveness of virtual reality in STEM education, particularly in environmental physics, sustainability learning, and engineering design. By integrating VR media into STEM-related activities, students cannot only meet specific curriculum objectives but also engage in engineering design processes within VIRRIC's virtual environment. This immersive platform enables students to apply engineering principles to design and optimize renewable energy systems, such as hydroelectric power plants (Rahmaniar et al., 2025). Through this hands-on experience, students develop problem-solving and critical thinking skills, fostering competencies related to global citizenship while addressing real-world sustainability challenges.

The positive outcomes observed in this research carry several implications for educational practice. Firstly, the incorporation of immersive simulations such as VIRRIC into science instruction is seen to help bridge the gap between theoretical knowledge and applied understanding. Secondly, these tools are considered especially valuable in schools where access to physical laboratories or real-world energy facilities is limited, as demonstrated by Hernández (2019) and Gebashe et al. (2025). It is hoped that the use of VR technology can support more equitable and inclusive learning opportunities across diverse educational settings.

Although the findings are considered promising, several limitations of this study need to be acknowledged. One of the challenges reported by students was dizziness during and after full-immersive VR use. This adverse effect has been identified as a drawback of this type of VR technology (Park & Lee, 2020). Some students were also observed to experience temporary nearsightedness following VR exposure, requiring the use of corrective lenses. However, wearing glasses while using VR devices was found to be uncomfortable, leading students to remove them while accessing VIRRIC media. These physical responses should be taken into account when designing and implementing VR tools in educational settings. Nevertheless, further medical evaluation remains necessary to confirm and better understand these effects.

Additional limitations include the relatively small sample size, which was drawn from a single educational context. As a result, the generalizability of the findings may be limited. Moreover, the intervention was relatively brief, with an emphasis on immediate learning outcomes rather than long-term retention or behavioral changes.

For future research, longitudinal studies should be conducted to examine the sustained impact of VR-based STEM instruction. Investigations involving more diverse student populations are also recommended, along with studies that explore how different teacher facilitation strategies influence the effectiveness of immersive learning environments. Furthermore, student responses across varying learning preferences should be explored, as these insights can inform the development of differentiated instructional approaches tailored to individual learners' needs.

CONCLUSION

Fundamental Finding : The results of this study show that implementing Virtual Reality Hydroelectric (VIRRIC) has a positive impact on students' learning outcomes and experiences. Immersive technologies such as VIRRIC help students develop a deeper understanding of abstract and complex physics concepts, such as energy conversion in hydroelectric power plants. The results of this study are associated with SDG 7 by increasing students' awareness, understanding, and motivation regarding the importance of renewable energy. There is great potential for VR-based tools such as VIRRIC to be further developed. This aims to overcome the gap between theoretical knowledge and practical application, especially in schools with limited access to physical laboratories and real-world energy-generation facilities. **Implication :** The results of this study are evidence in the use of immersive technology in STEM learning to support the development of 21st century skills. **Limitation :** Limitations such as small research samples and relatively short observation times can also be developed further in further research. **Future Research :** Even so, research problems such as the negative impact of dizziness after immersive VR use warrant further study. Overall, these results emphasize the importance of implementing VR-enhanced education to promote environmental awareness and global responsibility among learners.

AUTHOR CONTRIBUTIONS

Aminudin Zakaria handled data management, project coordination, and manuscript drafting. All listed authors have reviewed and approved the final version of this submission; **Mita Anggaryani** contributed to the conceptual framework, research design, and validation process; **Tinezia Cendani** was involved in methodology development, data analysis, sourcing references, and drafting the manuscript; **Nina Fajriah Citra** was involved in checking the readability of the paper and VR content.

CONFLICT OF INTEREST STATEMENT

The authors confirm that there are no conflicts of interest, either financial or personal, that may have influenced the content or outcome of this study.

ETHICAL COMPLIANCE STATEMENT

This manuscript complies with research and publication ethics. The authors affirm that the work is original, conducted with academic integrity, and free from any unethical practices, including plagiarism.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING
The authors acknowledge the use of digital tools, including AI-based technologies, as support in the research and writing stages of this article. Specifically, Grammarly was employed to improve linguistic aspects and readability in English. All outputs generated with digital assistance were critically evaluated and revised to ensure academic rigor and ethical standards were upheld. The final responsibility for the manuscript rests entirely with the authors.

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Aminudin Zakaria
Postgraduate Programe of Science Education, Universitas Negeri Surabaya
Jl. Ketintang, Surabaya, East Java, 60231, Indonesia
Email: 25030795021@mhs.unesa.ac.id

***Mita Anggaryani (Corresponding Author)**
Department of Physics Education Universitas Negeri Surabaya
Jl. Ketintang, Surabaya, East Java, 60231, Indonesia
Email: mitaanggaryani@unesa.ac.id

Tinezia Cendani
Postgraduate Programe of Education Technology, Universitas Negeri Surabaya
Jl. Lidah Wetan, Surabaya, East Java, 60213, Indonesia
Email: 24010905016@mhs.unesa.ac.id

Nina Fajriah Citra
Monash University
Wellington Rd, Clayton VIC 3800, Australia
Email: ncit0004@student.monash.edu