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

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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 Karangates 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