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Using Educational VR Systems to Promote Inquiry-Based Learning in Natural Science

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Abstract: The study aims to investigate whether educational VR can enhance inquiry-based learning (IBL) in natural science for primary students. Researchers integrated VR to a marine education curriculum with IBL theory in a quasi-experimental study to analyze students' learning outcomes and motivation. The results demonstrated that educational VR significantly improved students' learning outcomes, enhanced their motivation, and effectively developed their critical thinking and problem-solving skills. This study underscored the value and impact of educational VR in inquiry-based learning.

Keywords: Educational VR, Inquiry-Based Learning, Primary Students

1. Introduction and Literature Review

Technology offers advantages in natural science education. With the development of technology, the use of technology in global K-12 natural science education and research has grown exponentially, especially in studies involving simulation technology like Virtual Reality (VR) (Oliveira et al., 2019). Using VR in natural science education helps students focus on learning and improves learning outcomes (Hamilton et al., 2021). Moreover, VR immerses students in different scenarios, which can trigger emotional responses and encourage them e to take action, such as the conservation of the marine environment (Chiang, 2021). VR-based courses can also address issues in traditional natural science teaching, such as time, space, and safety, and fill in knowledge gaps according to the complexity of outdoor settings (Cheng & Tsai, 2019).

Combining VR with inquiry-based learning offers advantages. Inquiry-based learning is the most common method used in natural science education, emphasizing to activate students' participation through observation, questioning, investigation, and reflection (Dobber et al., 2017). When combined with VR, which offers interactive and immersive experiences, students are more willing to ask questions and try to solve problems, that enhances their inquiry skills and learning outcomes (Pedaste et al., 2015). Additionally, VR can shorten the time for inquiry-based learning, and reduce the pressure to keep up with the curriculum (Szalay & Tóth, 2016).

Integrating VR in marine education offers advantages. Marine education for primary students often faces challenges due to limited resources and policy constraints (Annette, 2017). VR technology can help overcome these obstacles by offering immersive experiences such as exploring marine research vessels, which are typically inaccessible. Through VR, students can gain a deeper understanding of marine environments, enhance their knowledge, problem-solving skills, and raise conservation awareness (Hamilton et al., 2021).

The educational VR designed for this study is based on the inquiry-based learning theory proposed by Pedaste et al. (2015) by incorporating the three steps: orientation, conceptualization, and investigation (Figure 1). The specific process is as follows.

- Orientation: In the VR environment, students confirm tasks with a virtual expert, stimulating their curiosity and understanding of the learning content and goals.
- Conceptualization: Students form causal hypotheses and build information and concepts related to the learning content within the VR.
- Investigation: Students test their hypotheses by using VR tools and conducting experiments or collecting and analyzing data according to the learning goals.

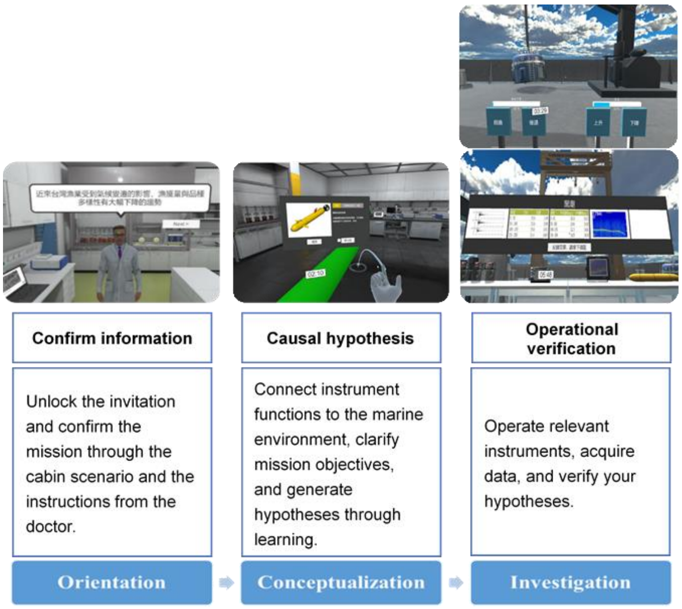

Figure 1. Educational VR of this study

This design not only prevents students from merely collecting and displaying data but also ensures effective learning. It helps students gain a deeper understanding of learning concepts and develop problem-solving and critical thinking skills.

Although VR technology is increasingly used in education, many studies do not integrate learning theories into their design and lack specific descriptions of learning outcomes (Radianti et al., 2020). This study aims to design an educational VR that incorporates inquiry-based learning theory into natural science courses for upper-grade primary students and explore its impact on students’ learning outcomes and motivation.

The study will address the following two questions:

- Can educational VR improve students' learning outcomes?
- Can educational VR enhance students' motivation for scientific inquiry, problem-solving abilities, and critical thinking skills?

2. Method

The research participants composed of 56 fifth graders from two classes in primary school in Taipei City. The study employed a quasi-experimental design, dividing the students into an experimental group and a control group. Below are explanations of the participants, experimental tools, and experimental design.

2.1 Participants

In each group, 28 students (15 boys and 13 girls, aged 10-11) were heterogeneously grouped. Since third grade, students began learning basic computer operations and using technology (e.g., iPads) to study natural science. In fourth grade, they used Cardboard for "streamflow VR" learning. Natural science courses were conducted in group discussions, where students clearly understood the focus of the learning tasks and how to concentrate on learning and discussion objectives.

2.2 Experimental tools

2.2.1 Learning Effectiveness

The test consists of 10 multiple-choice questions on ocean-related science education, based on Bloom's taxonomy:

- 3 questions on comprehension (e.g., "Which of the following is not an effect of global warming?")
- 3 questions on application (e.g., "What experimental equipment is needed to study the 'relationship between seawater temperature and salinity'?")
- 4 questions on analysis (e.g., "Which statement about 'climate change and the warming of seawater' is correct?")

The test is scored on a scale of 0-100. It was developed and validated by the first author and two experts with over 20 years natural science teaching experiences in the elementary school. The pre-test and post-test had the same questions but in different orders.

2.2.2 Motivation Questionnaire

The questionnaire developed by Huang & Chen (2017) includes four dimensions:

- Intrinsic Motivation: to assess students' focus and perceived relevance of the course. For example, "When I have the opportunity, I choose assignments that I can learn from, even though I can't guarantee a good grade."
- Extrinsic Motivation: to evaluate students' confidence and satisfaction with the learning process. For example, "Achieving a good grade in this course is my greatest satisfaction."
- Problem Solving: to understand students' thinking and strategies for problem solving. For example, "When solving problems, I first determine the type of problem and then apply different solutions."
- Critical Thinking: to measure students' personal growth and self-reflection. For example, "After achieving a goal, I ask myself how well I accomplished it."

Each dimension contains 3-5 items, rated on a 5-point Likert scale. With a Cronbach's $\alpha = 0.79$, the questionnaire provides an acceptable level of reliability for assessing students' learning motivation.

2.2.3 Learning Worksheets

The learning worksheet is used by both groups and includes three parts according to the steps of educational VR:

- Decoding the Invitation Letter: Understanding and interpreting the provided information.
- Instrument Operation: Learning how to use the equipment effectively.
- Experiment Design: Planning and designing the experiment.

2.2.4 Experimental Design

The experiment lasted for 180 minutes, with the experimental group (EG) using educational VR, while the control group (CG) received instruction via slides and web-based information (Figure 2). Both groups engaged in discussions, drew conclusions, completed pre-test and post-test assessments for learning effectiveness, and participated in a motivation questionnaire survey.

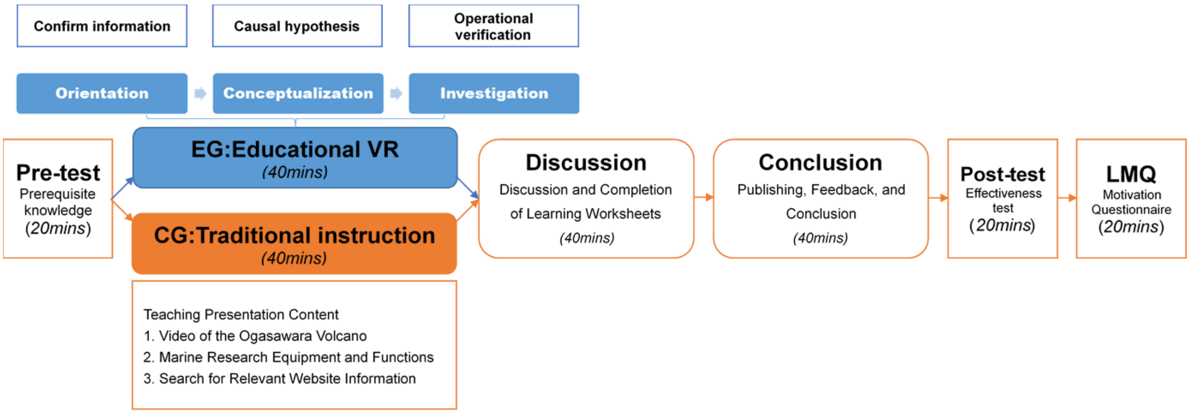

Figure 2. The Experimental Design

3. Results and Discussion

The study collected data from students' assessment of learning outcomes, motivation questionnaires, and conducted statistical analyses to address the two research questions based on the experimental results:

3.1 Can educational VR improve students' learning outcomes?

ANCOVA analysis was performed on the learning outcomes, and no significant difference was found in the pre-test scores between the experimental group and the control group. However, the post-test results revealed a significant difference in learning ability for this unit between the two groups ($F=1.29$, $p<.001$), with Cohen's $d > 0.8$, indicating that the educational VR intervention significantly improved the learning outcomes for the experimental group.

Additionally, analysis of the cognitive dimensions of the test showed that, except for the application dimension ($t=1.167$, $p>0.05$, Cohen's $d=0.33$), the experimental group demonstrated significant differences in the understanding ($t=2.06$, $p<0.05$, Cohen's $d=0.55$) and analysis ($t=4.36$, $p<0.001$, Cohen's $d>0.8$) dimensions (Table 1). This indicates that the educational VR intervention not only enhanced students' understanding but also facilitated their higher-level cognitive analysis skills.

Therefore, the results of this study validate the effectiveness of educational VR in improving students' learning outcomes and higher-level cognitive abilities, and the effect size data supports the significance of these findings.

3.2 Can educational VR improve students' motivation for scientific inquiry, problem-solving abilities, and critical thinking skills?

According to the statistical summary of the motivation questionnaires from both groups (Table 2), significant differences were observed in both intrinsic motivation ($t=5.801$, $p<0.001$) and extrinsic motivation ($t=3.621$, $p<0.001$, Cohen's $d>0.8$), indicating that educational VR significantly enhanced students' motivation for learning.

The data in Table 1 showed that educational VR intervention led to more active participation in scientific inquiry and increased learning motivation. This may be because educational VR can convey marine knowledge in a more concrete and vivid manner, immersing students in the learning context and generating interests and emotional resonance with the content, which ultimately translates into practical actions for protecting the marine environment (Annette, 2017; Chiang, 2021).

Table 2 also showed that the experimental group significantly outperformed the control group in problem-solving abilities ($t=6.280$, $p<0.010$, Cohen's $d>0.8$). The educational VR developed in this study not only allowed students to actively participate in marine research but also guided them through the three steps of inquiry-based learning, effectively enhanced their critical thinking (Forawi, 2016) and problem-solving skills.

Comparisons between the two groups in critical thinking abilities also showed significant differences (t=5.249, p<0.001, Cohen's d>0.8). The inquiry-based learning theory aims to cultivate students' ability and competitiveness in dealing with an uncertain and changing world (Kuhlthau et al., 2015). The immersive and interactive learning environment of the educational VR provided students with opportunities to explore, experiment, and discover, thereby guiding them to think more deeply and solve real-world problems.

Table 1. *t-tests for cognitive dimensions of learning effectiveness between EG & CG*

Group	Dimension	Mean(SD)	t
EG	Understanding(U)	22.86(8.55)	2.063*
CG		17.86(9.57)	
EG	Application (APP)	13.96(9.56)	1.167
CG		11.07(8.75)	
EG	Analysis (ANA)	23.21(9.05)	4.357***
CG		12.14(9.95)	

**p* $<$.05, ****p* $<$.001*

Table 2. *t-test for questionnaire dimensions between EG and CG*

Dimension	EG(n=28)	CG(n=28)	t
	M(SD)	M(SD)	
Intrinsic motivation	12.54(1.62)	9.64(2.29)	5.801***
Extrinsic motivation	11.96(1.55)	9.79(2.78)	3.621***
Problem-solving tendency	21.18(2.36)	21.18(2.36)	6.280***
Critical thinking tendency	19.71(3.20)	15.04(3.47)	5.249***

****p* $<$.001*

4. Conclusion

This study used ANCOVA and t-test analyses to compare pre- and post-test results between the experimental group and the control group. It was found that the experimental group significantly outperformed the control group in terms of learning outcomes, motivation, problem-solving abilities, and critical thinking skills. This confirms that integrating VR with inquiry-based learning (IBL) not only provides high-quality scaffolding for inquiry learning but also effectively develops students' scientific skills, understanding of scientific concepts, and promotes scientific literacy (Constantinou et al., 2018), with a positive and significant impact on students' learning outcomes (Sung et al., 2016). Overall, this study demonstrates the potential of combining educational VR with inquiry-based learning and highlights its importance in reducing teacher workload, promoting student autonomy, and enhancing learning engagement.

However, the study also faced some limitations, such as the limited number of HMD devices, which allowed only a few students to use them at a time and may have affected the learning outcomes. Additionally, different learning theories may yield different results, so future research should incorporate other theories to further validate the feasibility of these findings.

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