PROCEEDINGS OF SCIENCE

What is learned from the IceCube Virtual Reality Game a case study with Thai students

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Discover IceCube is a virtual reality (VR) experience developed by an interdisciplinary team at the University of Wisconsin-Madison. It allows the user to travel to the IceCube Neutrino Observatory at the South Pole and take a fanciful flight to a black hole that produced the detected neutrino. It provides an engaging activity to learn about IceCube, neutrinos, multimessenger astrophysics, and extreme sources. The prebuilt Discover IceCube virtual experience was translated into Thai as means of broadening the audience for this work. To test the impact of this modified experience, students were given a pre-test and post-test. The data showed that the experience provided a means to increase students' understanding of concepts such as neutrinos, physics, and IceCube. Furthermore, the VR experience also demonstrated an increased Thai students' interest in physics and science.

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1. Introduction

IceCube is a gigantic three-dimensional neutrino observatory located at the Geographic South Pole. It comprises 5,160 strategically positioned Digital Optical Modules (DOMs) within a volume of approximately one cubic kilometer of ice. IceCube is designed to detect high-energy neutrinos and cosmic rays within the energy range of TeV to PeV , while also possessing the ability to measure high-energy astrophysical neutrinos [1, 2]. A schematic representation of IceCube can be seen in Figure 1.

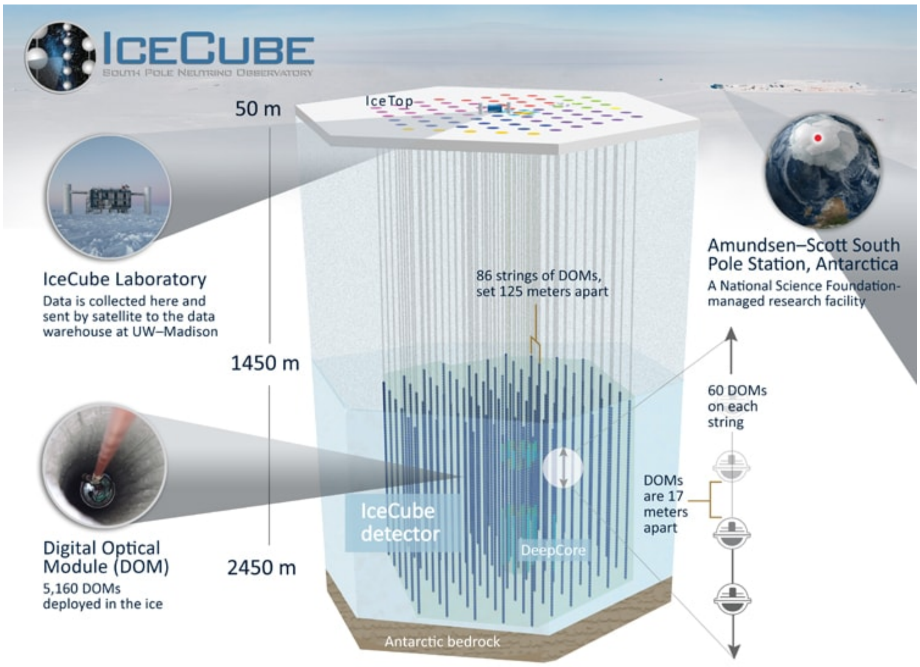

Figure 1: The IceCube Neutrino Observatory is situated approximately 2,450 meters below the ice surface at the Geographic South Pole. [Image credit: https://icecube.wisc.edu/science/icecube/.

Due to the challenging accessibility of IceCube's location, Virtual Reality (VR) offers an alternative means to experience the unique setting and missions of IceCube. The Wisconsin Institute for Discovery (WID) and Wisconsin Center for Education Research at the University of Wisconsin-Madison have developed IceCube Virtual Reality, known as IceCube VR. This immersive virtual experience has been exhibited at WID and extensively tested with diverse audiences in Madison [3]. The test results revealed that IceCube VR effectively stimulated the audience's acquisition of knowledge and understanding.

The Wisconsin IceCube Particle Astrophysics Center (WIPAC) is a research organization dedicated to conducting impactful projects focused on significant discoveries associated with IceCube. Apart from research, WIPAC is actively involved in promoting science through Education and Outreach activities. To broaden the accessibility of IceCube VR, WIPAC has established a collaboration with Thai researchers who have been actively involved as members of IceCube since 2021. The Thai research group had the privilege of experiencing IceCube VR during our visits to the Summer Student Program in 2022. This immersive encounter has inspired us, and we are now driven to increase the awareness of and enthusiasm for science among Thai students using the remarkable discoveries made by IceCube.

In this study, our primary aim was to translate IceCube VR into the Thai language and offer Thai students the opportunity to engage with the localized version of IceCube VR. As we currently possess only one VR device, we accommodated students who did not have access to VR devices by broadcasting the VR experience through projectors connected to high-quality speakers. To assess the impact of these experiences, we conducted Pre-test and Post-test assessments and performed t-Test analyses. The following sections of this work will provide detailed explanations of our research methodology, data analysis, results, and discussion of our findings.

2. Methodology

The IceCube VR experience offers an immersive and captivating game that transports users to the real-life setting of IceCube at the South Pole in Antarctica. Within this virtual environment, users embark on a mission to collect vital physical observations. Additionally, IceCube VR takes users on a fascinating journey through outer space, providing insights into the path traveled by neutrinos. Ultimately, users are guided to one of the sources of neutrinos [4], specifically a supermassive black hole. Through their engagement with IceCube VR, users acquire knowledge about neutrinos, physics, and the particle detection capabilities of IceCube itself.

After translating IceCube VR into the Thai language, our group organized an event called the 'Thai IceCube VR on Tour Experience.' This initiative involved visiting two universities, one high school, and one academic institution. During these events, we administered a Pre-Test to the participating students without providing any prior teaching. Subsequently, the students were given the opportunity to experience the Thai IceCube VR using either the Oculus Quest 2 device (referred to as 'VR') or by watching the VR broadcast through projectors (referred to as 'Projector'). Following their VR experience, the students underwent a Post-Test to evaluate the impact of their engagement. Furthermore, we delivered a comprehensive overview of cosmic rays, neutrinos, and the IceCube observatory through a video clip, accessible at `https://www.youtube.com/watch?v=pjhBbj032yc`. Occasionally, when time permitted, we also conducted a Q&A session. For an example photograph captured during one of the events, see Figure 2.

2.1 List of questions for the test

We conducted a set of multiple-choice questions to evaluate the students' fundamental knowledge in the areas of neutrinos, physics, and IceCube. Furthermore, the students were requested to rate their comprehension of neutrinos and IceCube in the category of "Basic Understanding." We included curiosity-related Yes-No questions about science and IceCube as part of the Post-Test. The specific questions are listed below:

Basic Understanding - Multiple choices:

1. What is a neutrino?
2. What is the source of a neutrino?
3. Where is IceCube located?
4. What can travel through Pluto?
5. Which one is the heaviest?

Figure 2: IceCube VR experience using VR (shown on the left) and Projector (shown on the right) platforms.

Basic Understanding - Rate your understanding about:

1. Neutrinos
2. IceCube

Curiosity - Rate your interest:

1. Are you interested in science more after experiencing IceCube VR?
2. Do you want to know more about IceCube after experiencing IceCube VR?

These questions were formulated to evaluate the student's general understanding, interest, and curiosity regarding neutrinos, IceCube, and science.

2.2 Data Analysis

We used a paired t-test analysis to evaluate the results of the Pre-test and Post-test for students who exclusively experienced IceCube either through VR or through the Projector. This analysis aimed to quantify the knowledge acquired after each respective experience. Additionally, we performed an independent t-test analysis to compare the results of students who experienced IceCube via VR with those who experienced it using the Projector. The objective of this analysis was to identify any notable differences in the knowledge gained between the two different modes of experience.

The hypotheses for this study are as follows:

A Students who engage in these activities will gain knowledge.

B There will be a significant difference in the level of basic understanding gained between the students who experienced IceCube via VR and those who experienced it via the projector.

C Students who participated in the VR experience will demonstrate a higher level of curiosity compared to those who experienced IceCube through the projector.

Table 1: Statistics of t-Test: Paired Two-Sample Means. The significance level is set at 0.05.

Factor	Pre-test		Post-test		Gain	p-value	t_{stat}
	Mean	S.D.	Mean	S.D.			
Basic Understanding - Multiple choices							
VR N = 31	3.2	1.1	4.3	0.8	1.1	< 0.001	-6.15
Projector N = 101	2.7	1.1	4.2	0.9	1.6	< 0.001	-13.24
Basic Understanding - Neutrinos							
VR N = 31	1.5	1.4	3.8	1.3	2.3	< 0.001	-7.60
Projector N = 101	1.2	1.4	3.5	1.4	2.3	< 0.001	-15.46
Basic Understanding - IceCube							
VR N = 31	1.1	1.6	3.8	1.2	2.7	< 0.001	-8.57
Projector N = 101	1.0	1.0	3.4	1.1	2.4	< 0.001	-15.22

3. Results and Discussion

3.1 Hypothesis A: Students who engage in these activities will gain knowledge.

There are three pieces of evidence that support Hypothesis A, all of which are evaluated using a paired-sample t-test between the Pre-test and Post-test. For all the analyses, we used a significance level of 0.05. A statistically significant test result, with a p-value ≤ 0.05, indicates that the null hypothesis is false or should be rejected. Conversely, if the p-value is greater than 0.05, it implies that no significant effect was observed.

The first piece of evidence examines Basic Understanding through multiple-choice questions, which are listed in sub-section 2.1. The p-values obtained for VR (N=31) and Projector (N=101) are both less than 0.001, indicating a significant gain in knowledge from both experiences. The gain values for VR and Projector are 1.1 and 1.6, respectively. The gain of VR is lower because students who engage with VR have a deeper understanding of astronomy, resulting in higher scores on the Pre-test. In addition to the t-Test analyses, we also calculated the correctness score percentage, which is defined as the ratio of the number of correct answers out of 5 to the total number of answers ($5 \times N$). For the pre-test, the correctness score percentages are 64% for VR and 53% for the Projector. Similarly, for the post-test, the correctness score percentages of both modes are both 85%. The results are presented in Figure 3. Interestingly, there is no significant difference in the Post-test results between students who experienced VR and those who used the Projector.

The second piece of evidence focuses on the Basic Understanding of Neutrinos. In this test, students rated their understanding on a scale of 0 (none) to 5 (expert). Once again, both VR (N = 31) and Projector (N = 101) yielded p-values of less than 0.001, which offers additional substantial evidence of a significant improvement. Furthermore, both VR and Projector demonstrated identical gain values of 2.3.

Lastly, the third piece of evidence examines the Basic Understanding of IceCube. Similarly, students rated their understanding on a scale of 0 to 5. The p-values for VR (N=31) and Projector (N=101) are less than 0.001, indicating a significant gain in knowledge. The gain values for VR and Projector are 2.7 and 2.4, respectively. A comprehensive summary of all the results can be seen in Table 1.

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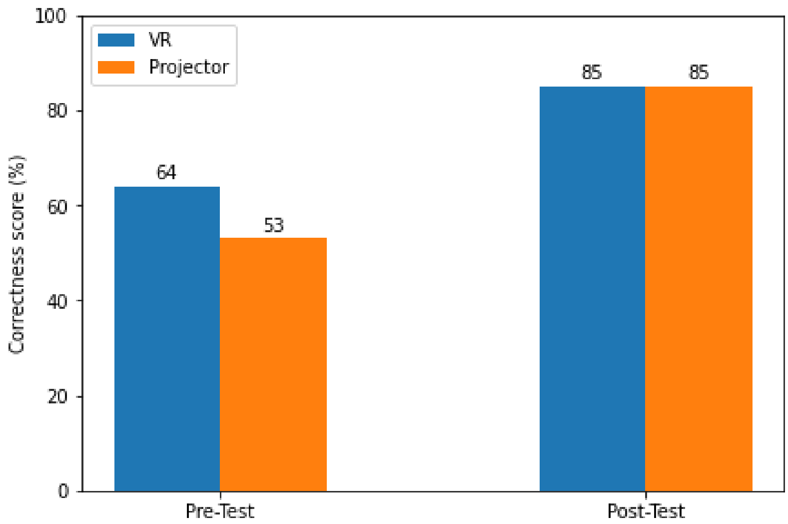

Figure 3: The correctness score percentage of students who experienced VR versus those who used the projector.

3.2 Hypothesis B: There will be a significant difference in the level of basic understanding gained between the students who experienced IceCube via VR and those who experienced it via the projector.

For Hypothesis B, we employed an independent t-Test to compare the gain in students' knowledge between those who experienced VR and those who used the Projector. A significance level of 0.05 was used for the analysis. The summarized results can be found in Table 2.

Regarding the gain from multiple-choice questions, the p-value is 0.026, which is less than 0.05. This indicates a significant increase in knowledge and a significant difference between the VR and projector modes. However, for the gain in rating understanding of neutrinos, the p-value is 0.983, which is greater than 0.05. This suggests that there is no significant difference between the students who experienced VR and those who used the projector regarding their understanding of neutrinos. Similarly, for the gain in rating understanding of IceCube, the p-value is 0.399, also greater than 0.05, indicating no significant difference between the two modes.

The gain value for students learning through VR tends to be lower compared to those learning through a projector. This could be attributed to the fact that most students who engage with VR already possess a pre-existing curiosity and have basic background knowledge about particle physics and astrophysics. When rating the level of basic understanding of the neutrino and the IceCube, there was no significant difference in the gain value of knowledge.

3.3 Hypothesis C: Students who participated in the VR experience will demonstrate a higher level of curiosity compared to those who experienced IceCube through the projector.

For Hypothesis C, we collected the students' responses of "yes" or "no" and calculated the curiosity percentage by dividing the number of "yes" responses by the total number of answers. The results, presented in Figure 4, indicate that both the students who experienced VR and those

Table 2: Statistics of t-Test: Two-Sample Assuming Equal Variances. The significant level is 0.05.

Factor	VR		Projector		p-value	t_{stat}
	Gain (N=31)	S.D. (N=31)	Gain (N=101)	S.D. (N=101)		
Basic Understanding - Multiple choices	1.1	1.0	1.6	1.2	0.026	-2.26
Basic Understanding - Neutrino	2.3	1.6	2.3	1.5	0.983	-0.02
Basic Understanding - IceCube	2.7	1.7	2.4	1.6	0.399	0.85

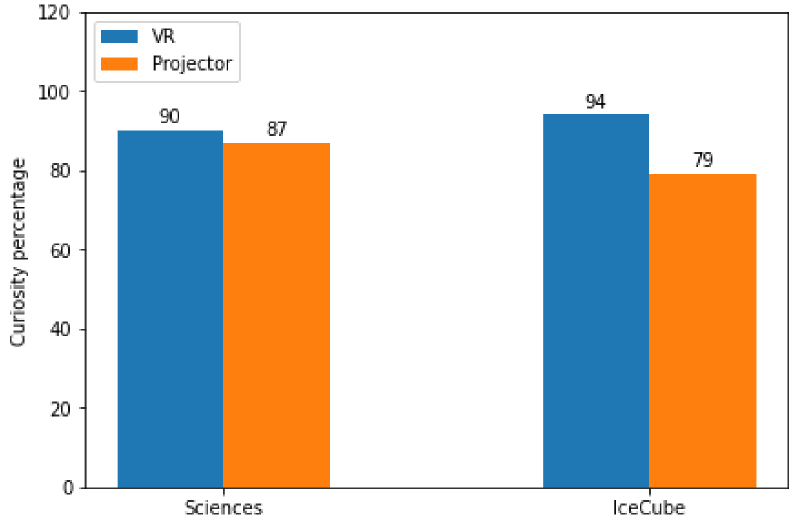

Figure 4: The curiosity levels of students who experienced VR versus those who used the projector.

who used the Projector were engaged in Science and IceCube. Furthermore, it is evident that the students who experienced VR exhibited a higher level of curiosity compared to those who used the Projector.

4. Conclusions

The IceCube VR experience is an interactive game that transports users to the icy landscape of the South Pole in Antarctica, home to the remarkable IceCube facility. Within this virtual world, users embark on a thrilling mission to collect crucial physical observations. Furthermore, IceCube VR provides a captivating journey into space, allowing users to witness the journey of neutrinos through the cosmos. The ultimate destination is a black hole, which serves as one of the sources of these elusive particles. By engaging with the IceCube VR, users acquire knowledge about neutrinos, physics, and the particle detection capabilities of IceCube.

To evaluate the impact of the VR experience, we employed a combination of tests and surveys. Initially, students were presented with a series of multiple-choice questions to assess their basic understanding of neutrinos, physics, and IceCube. Additionally, students rated their comprehension of neutrinos and IceCube both before and after engaging with the VR experience. Furthermore, the post-test included curiosity-based questions pertaining to science and IceCube.

For Hypothesis A, the results consistently revealed p-values below the designated significance level for all cases, indicating a significant improvement in knowledge among students following their participation in the VR experience. These findings were further supported by the correctness score.

Regarding Hypothesis B, although there was a notable increase in knowledge based on the multiple-choice tests, no significant differences were observed between the two modes of experience (VR versus Projector). This implies that both approaches were equally effective in enhancing understanding.

For Hypothesis C, both groups of students, whether they experienced the VR or Projector, expressed a heightened interest in science and the IceCube project. This indicates that the IceCube VR successfully engaged Thai students in physics, science, and the subject of IceCube.

In summary, the findings demonstrate that the IceCube VR experience effectively enhanced students' knowledge and fostered their interest in the field of physics, science, and the particle detection capabilities of IceCube.

In the future, our plan is to exhibit these VR experiences at a science exhibition in Thailand, with the intention of expanding from a single device to multiple devices to accommodate a larger number of visitors. To enhance the accessibility of the exhibit, we are also planning to create instructional videos and materials that provide simple and concise instructions, enabling the exhibition audience to engage with the VR experiences independently. By broadening our focus to national exhibitions, we aim to ensure the continuous development of scientific knowledge related to neutrinos and IceCube, fostering a deeper understanding among attendees.

5. Acknowledgments

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