

Transforming Science Education: The Effect of Immersive Technology on Student Performance

¹Ani Susanti, ²Awanis Hidayati, ³Hendra Wijaya, ⁴Novaria Nusantara, ⁴Arie Susanty, ⁴Fazhar Restu Fauzi

¹Universitas Ahmad Dahlan

²Universitas Nahdlatul Ulama Kalimantan Barat

³SMK Immanuel Pontianak

⁴SEAMEO SEAMOLEC

[*ani.susanti@pbi.uad.ac.id](mailto:ani.susanti@pbi.uad.ac.id)

Abstract

This study examines the influence of immersive technology on student learning outcomes, emphasising its efficacy in improving comprehension of intricate scientific ideas, particularly the solar system. A quasi-experimental approach was utilised, featuring an experimental group utilising immersive technology tools and a control group receiving conventional video-based teaching. Data were gathered via pre-tests and post-tests to evaluate knowledge acquisition, in addition to observations and questionnaires to measure student involvement and participation. The results revealed significant improvements in both groups, with the control group achieving higher post-test scores, potentially due to the familiarity and structured nature of the traditional methods. However, the experimental group demonstrated the unique benefits of immersive technology, particularly in visualizing abstract concepts and fostering interactive learning experiences. These findings suggest that while immersive technology has substantial potential, its effectiveness depends on the context and implementation. Future research should explore its long-term impact and strategies for optimizing its integration into diverse educational settings.

Keywords: Experiential Learning, Learning Comprehension, Immersive Technology, Science Education

Background

Immersive technologies are progressively being integrated in education, promoting transformation across various levels and settings. Immersive technologies offer experiential learning opportunities, optimize learners' cognitive growth and develop intrinsic motivation that help students visualize abstract concepts and engage with realistic or semi-realistic experiences (Bhatia & Hesse, 2023; Poupard et al., 2024; Trigos & Tamayo, 2023). For instance, the use of Immersive Virtual Reality (IVR) in science classrooms by generating intelligent artificial robot supporting students develop a conceptual understanding of science knowledge include leverage, animals and plants (Liu et al., 2020).

Immersive technology grasps tools such as Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), which create the real and virtual worlds into dynamic and attractive environments. Immersive technologies have been reported to improve student performance, motivation, and engagement such as in STEM education (Tene, Marcatoma Tixi, et al., 2024), professional training (Wang, 2024; Yakovleva, 2022) and intellectual disability learning (Iatraki & Mikropoulos, 2022). Additionally, they promote the growth of social and emotional competencies that are essential for success in both higher education and workforce (Tene, Marcatoma Tixi, et al., 2024).



Previous studies have reported that learners' age and cognitive characteristics can be the variable of the effectiveness of immersive technology integration in education. MR technology has been reported to assist younger students more (Petruse, Grecu, Gakić, et al., 2024). Although a more rigorous theoretical foundation is still needed, systematic reviews show that integrating immersive technology into education across a range of age groups increases successful learning. Analysis of 64 studies (2018–2023) on immersive technologies in elementary education emphasizes how they improve learning, particularly in science subject, and how important it is to have more solid theoretical frameworks and pay attention to the cognitive and affective experiences of students (Francisco Javier et al., 2024). While systematic review of 33 studies conducted from 2012 to 2021 in secondary education setting examines the application of immersive technologies in K-12 English language learning, emphasizing their capacity to generate simulated environments for language acquisition, improve learner attitudes and interdisciplinary skills, and evaluate learning efficacy through various research methodology, while also highlighting a notable deficiency in the theoretical foundation of these studies (Weng et al., 2024). While in higher education, systematic review of 12 studies (2017–2021) on mixed reality in higher education reports the potential of augment learning, especially in medical and engineering disciplines via 3D visualization and manipulation, while also addressing its challenges and prospects for innovative pedagogical practices and curriculum development (Sviridova et al., 2023).

Comparative analyses have been completed in a number of studies to assess the effectiveness of immersive technologies vs conventional teaching resources. A study conducted in Mostar, Bosnia and Herzegovina highlights that age-related preferences and the need for specialized instructional approaches in anatomy education by comparing the efficacy of traditional teaching methods using PowerPoint slides with mixed reality instruction via HoloLens 2; this study also found that mixed reality was more effective for younger students while traditional methods were better for older participants (Petruse, Grecu, Chiliban, et al., 2024). Another study in Taiwan compares traditional lecturing vs immersive technology learning found that augmented reality (AR) significantly improved English vocabulary learning performance and instructional materials motivation in 42 fifth-grade students (Tsai, 2020). Other study in China setting provided empirical support and useful insights for integrating immersive virtual reality (IVR) into middle school science instruction by showing that, when compared to traditional teaching methods, IVR lessons greatly increased sixth-grade students' academic achievement, engagement, and technology acceptance (Liu et al., 2020).

A number of challenges prevent immersive technologies from being widely adopted and used effectively in education. Many institutions, especially in developing countries, find it difficult to pay for the high initial investment needed for equipment like VR headsets and AR devices, which is further compounded by continuing costs for maintain, updates, and content creation (Stojšić et al., 2018). Accessibility is supplementary restricted by inadequate infrastructure, particularly in rural or underfunded settings, which includes high-speed internet and sophisticated computing resources (Stojšić et al., 2018). Another important obstacle that could suspend the adoption is the requirement for intensive training and collaboration to give teachers and students the technical knowledge required to use these tools efficiently (Crolla et al., 2024). Another significant problem is the difficult and specialized process of producing good instructional materials that meet curriculum requirements, since teachers are further burdened by the lack of easily accessible resources (Gaspar et al., 2020). These technologies must be carefully merged into current curriculum to improve learning without overwhelming students or conflicting from the goals (Kuhail et al., 2022). Finally, prolonged use of immersive technology might lead to health problems including motion sickness and eye strain, which directly affect students' wellbeing and restrict their helpfulness (Kong & Feng, 2024).

This study explores how immersive technology can improve educational understandings. Through an analysis of its effects on student comprehension, it seeks to determine how successfully this technology improves learning results. In accordance with these objectives, the study aims to answer the following questions: Do students acquire better learning comprehension in an immersive technology-based classroom than in a classroom in which video-based teaching methods are used?

This research enhances the current dialogue regarding innovative teaching methodologies and their potential impact on future educational practices. It seeks to offer essential information to stakeholders in utilising immersive technology to create new and successful learning environments, solving current difficulties in education.

Research Method

Research Design

This research employed a quasi-experimental approach to observe the effect of immersive technology on instructional results. The research design included experimental and control groups, with the experimental group integrating immersive technology into their learning activities, whereas the control group use conventional approaches using YouTube video as media display. Data gathering included pre- and post-tests to assess understanding levels. This method enabled a thorough analysis of the advantages and drawbacks of immersive technology, enhancing an evidence-based understanding of its effectiveness in educational environments.

Hypothesis

The hypothesis of this research is that the use of immersive technology in instructional activities will significantly enhance students' understanding compared to conventional approaches using video as a media display.

Participants

The participants in this study comprised students from a private vocational secondary high school in West Kalimantan, Indonesia selected through purposive sampling. The sample included 68 individuals age 15-16 years old from two classes divided into an experimental group and a control group. The experimental group (XTKJ1) of 35 students (30 males and 5 females), engaged with immersive technology tools as part of their learning activities, while the control group (Class XAKL) consisted of 33 students (13 males and 20 females), used YouTube video as the learning media. The majority of students possessed no prior exposure to immersive technology, with their experience primarily restricted to fundamental multimedia tools.

The teacher for the experimental group was a male educator with educational qualification of bachelor in engineering and magister in management and sufficient experience in utilizing technology in teaching. He had received training in the use of immersive technology tools and was involved in designing interactive and technology-enhanced learning activities. His approach emphasized integrating digital tools to foster student engagement and comprehension. The control group was taught by a female teacher with bachelor qualification in accounting and adequate experience in systematic teaching methods. She specialized in delivering structured lessons using contextual pedagogical strategies, focusing on direct instruction and interactive discussions. Although their educational background was not from science education, both teachers were trained and skilful professionals capable of delivering students-centered instruction tailored to their respective teaching approaches, utilizing an experiential learning framework to foster active participation and meaningful engagement.

Rationale for Selecting Solar System as the Research Focus

This study focusses on the Solar System due of its abstract concepts, which can be difficult for students to comprehend using conventional teaching techniques. These encompass the extensive distances, the intricate interactions among celestial bodies, and the detailed attributes of planets and the Sun. Immersive technology, including virtual and augmented reality, is especially effective in tackling these difficulties by offering students interactive, visual, and experiential learning experiences. Immersive environments enable students to interact with the Solar System more concretely, visualising planetary motion, spatial relationships, and celestial phenomena that are normally challenging to comprehend. This method enhances students' comprehension of abstract concepts and fosters their enthusiasm and curiosity, rendering the study of the Solar System more approachable and entertaining.

Measurement Tools

This study utilised pre-test and post-test assessments consists of 20 multiple-choice questions aimed at evaluating students' understanding of astronomical concepts, particularly the attributes of celestial bodies and solar system occurrences. The pretest and post-test content had been designed to be similar, ensuring that both evaluations encompassed the same subject matter. The sequence of the questions was randomised, resulting in a variation in the order of items between the pre-test and post-test. The randomisation aimed at minimising potential biases or memorisation effects resulting from the repeated presentation of identical questions in a predetermined sequence.

The test was designed in Indonesian language by the science school teacher team from the research site and assigned to the students via online using Microsoft form. The pre-test, sought to assess the participants' foundational knowledge prior to the instructional intervention, whereas the post-test examined the learning results following the completion of teaching sessions by both the experimental and control groups. Both assessments encompassed subjects like the composition and characteristics of the Sun, the physical qualities of the planets, and their functions within the solar system. The study seeks to assess the effectiveness of immersive technology in improving students' comprehension of the subject matter by comparing the outcomes of these assessment.

The test has been subjected to readability testing and content validity reviews to guarantee the quality and relevance. The readability review was performed to find out if the language and structure of the questions were suitable and comprehensible for the students. Readability testing involved 21 non-experimental and control students. Those students, varied in academic competence, reviewed the test to determine if the language, organisation, and clarity of the questions were acceptable and understandable. Their input made the test clear and accessible to the target students.

Intervention Procedure

The instructional methodology for this experimental research technique adheres to a systematic framework grounded in Kolb's Experiential Learning Cycle. In this cycle, students initially participate in a practical experience, subsequently reflect on it, cultivate theoretical insights, and then implement these concepts in real-world contexts to evaluate and enhance their understanding (Kolb, 2015). This cycle facilitates the conversion of passive learning into active involvement, fostering enhanced comprehension and skill acquisition.

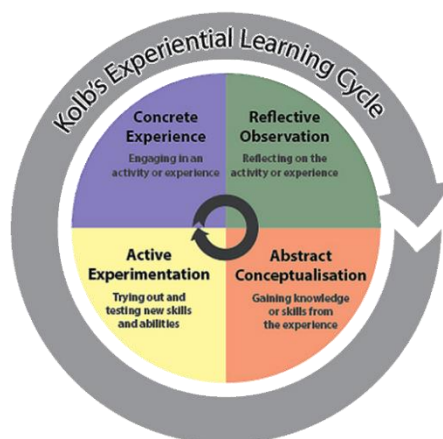


Figure 1. Kolb's Experiential Learning Cycle

The lesson plan was developed by the teacher responsible for the science subject and was later approved by a panel of experts. The validation procedure confirmed that the lesson plan was pedagogically systematic, connected with the curriculum, and successfully structured to achieve the learning objectives. The expert team evaluated the content, structure, and pedagogical approaches to ascertain the plan's quality and suitability for student learning, then informed the evaluation result in a meeting with the teachers prior to the intervention. The expert panel comprised two science teachers and a lecturer in teaching approaches. The collaboration aimed to ensure the lesson plan was both pedagogically robust and practically applicable to achieve the desired learning outcomes.

Experimental Group

The initial phase involved creating the virtual environment, which included metaverse rooms, functional VR equipment, and interactive resources, such as 3D planetary models and tasks tailored to the solar system theme. This creation was designed by a group of teachers and educational volunteers. The next phase, students engaged in a 25-minute orientation session to acquire insights into immersive learning and virtual technologies. The teacher introduced the metaverse platform, including how students would navigate the virtual environment, interact with 3D models, and complete solar system assignments. The purpose of this orientation was to



guarantee that students were adept in the technology and ready for the forthcoming learning. The orientation session was few days before the classroom intervention day.

During the intervention day, the teacher opened the course with a greeting and a collective prayer. The initial portion of the lesson plan aligned with Kolb's Experiential Learning Cycle by laying the groundwork for the **Concrete Experience** stage. The teacher subsequently activated students' prior knowledge through guided enquiries and outlined the session's objectives. The principal activities, lasting around 70 minutes, engaged students in immersive learning experiences.

In the next stage, **Reflective Observation**, students participated in teacher-guided group discussions to share and analyse their findings. In the **Abstract Conceptualisation** phase, the teacher clarified theoretical elements, enabling students to link their virtual observations with scientific principles. During the **Active Experimentation** phase, students collaborated to create and present simulations or models based on their virtual exploration, demonstrating their understanding of the solar system. The session concluded with a closure phase, whereby the teacher guided a reflective discussion on the learning outcomes, provided feedback on the students' presentations, and evaluated their understanding through a short quiz.

Control Group

The control group implemented a pedagogical method incorporating video technology that followed Kolb's Experiential Learning Cycle, thereby enhancing student engagement through four fundamental stages. The session started with the teacher showed educational video content from YouTube, featuring visuals of the solar system, planets, and their characteristics, which were presented via projectors or laptops. In the **Concrete Experience** level, students watched a movie that visually and audibly illustrated the solar system, allowing them to analyse the characteristics of planets, the sun, and their interactions.

Following the video, students engaged in **Reflective Observation**, wherein they discussed their observations and shared insights within groups, so facilitating the understanding of the material they had just acquired. In the **Abstract Conceptualisation** phase, the educator guided students in linking their reflections to scientific concepts, like planetary characteristics and orbits, encouraging them to formulate theories based on the video content. During the **Active Experimentation** stage, students applied their knowledge to create models or presentations based on the information obtained, allowing them to evaluate and improve their understanding. By following these processes, the control group employed video technology to enhance a comprehensive learning process that fostered conceptual understanding of the solar system in accordance with Kolb's model.

Data Analysis

The data analysis contained some statistical tests to assess normality, homogeneity, and differences in learning results both within and between the experimental and control groups. A significance level of $\alpha < 0.05$ was employed as the criterion for establishing statistical significance.

Normality Test

A One-Sample Kolmogorov-Smirnov test was carried out to evaluate the normal distribution of the pre-test and post-test scores data. This test is essential for assessing the appropriateness of parametric statistical analyses for the data. Normality was assessed independently for the experimental and control groups in within-group analysis. The combined post-test data from both groups were evaluated to confirm the suitability of parametric approaches for intergroup comparisons.

Homogeneity Test

Levene's test for equality of variances was employed to assess the statistical equivalence of the variances between the experimental and control groups. This step assured that the two groups had equal variability in their scores, a prerequisite for doing independent samples t-tests.



T-Tests

This study employed t-test to evaluate the effectiveness of immersive technology compared to conventional video-based instruction through analysing variations in student performance. An independent samples t-test was conducted to compare the post-test scores of the experimental and control groups, assessing whether students

exposed to immersive technology demonstrated significantly better learning improvements than those instructed by traditional video methods.

Findings

This section displays the result of SPSS statistical testing. The Table 1 below displays the statistical results from the normality and homogeneity testing.

Table 1. Normality and Homogeneity testing result

Test	Experimental Group	Control Group	Between-Group
Normality Test	Pre-Test: Normal ($p=.074$ $p = .074$)	Pre-Test: Normal ($p=.200$ $p = .200$)	Combined Post-Test: Normal ($p=.098$ $p = .098$)
	Post-Test: Normal ($p=.200$ $p = .200$)	Post-Test: Non-normal ($p=.003$ $p = .003$)	
Homogeneity Test	—	—	Homogeneous ($p=.104$ $p = .104$)

The normality test evaluated the appropriateness of the data from both groups for parametric statistical analysis. The pre-test and post-test scores for the experimental group demonstrated a normal distribution, thus affirming the data's trustworthiness for subsequent parametric analysis. The control group's pre-test scores exhibited a normal distribution; nevertheless, its post-test scores displayed several anomalies. Nonetheless, the combined data from both groups' post-test scores met the criteria for normality, facilitating an equal assessment of their performance.

The homogeneity test verified that the variation between the experimental and control groups was homogeneous, as evidenced by $p = .104$. This result indicates that the score variability between the two groups was not statistically different, confirming their comparability in performance variances.

Table 2 below displays the mean score comparison and t-test result.

Table 2. Mean Comparison and T-Test Result

Group	Mean Pre-Test	Mean Post-Test	Mean Difference	Hypothesis Test Result
Experimental	43.43	52.14	+8.71	Significant difference ($p=0.032$ $p = 0.032$)
Control	50.88	75.76	+24.88	Significant difference ($p=0.000$ $p = 0.000$)
Between Groups	N/A	Experimental: 52.14, Control: 75.76	N/A	Significant difference ($p=0.000$ $p = 0.000$)

The mean pre-test score of 43.43 increased to a mean post-test score of 52.14, with a mean difference of +8.71 points. This improvement was statistically significant ($p=0.032$), indicating the effectiveness of immersive technology in solar system learning. While the mean pre-test score of 50.88 increased to a mean post-test score of 75.76, with a mean difference of +24.88. This improvement was also statistically significant ($p=0.000$), showing the effectiveness of YouTube video learning media to support solar system understanding.

The post-test mean score comparison between the experimental group (52.14) and the control group (75.76) revealed a statistically significant difference ($p=0.000$), representing higher learning gains in the control group.

Discussion

This study aims to assess the effectiveness of immersive technology in improving students' learning comprehension about abstract concepts especially in solar system, and it shown that immersive technologies provide important educational advantages. The findings support earlier research indicating that immersive technologies, including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), foster dynamic and engaging learning environments that enhance student performance, motivation, and engagement (Bhatia & Hesse, 2023; Poupard et al., 2024; Trigos & Tamayo, 2023). These technologies have demonstrated remarkable effectiveness in STEM teaching (Tene, Marcatoma Tixi, et al., 2024) and can facilitate the learning of important social and emotional competencies (Tene, Guevara, et al., 2024). This study showed that immersive technology, especially in scientific education, offers students an engaging and experiential learning opportunity, aiding them in visualising intricate ideas such as planetary motion and the interrelations among celestial objects. This study's findings support existing literature highlighting the power of immersive technology to facilitate students' comprehension of abstract scientific topics (Liu et al., 2020).

Surprisingly there was also a notable improvement in the control group, which relies on YouTube videos for learning. This research demonstrates how well-structured traditional teaching approaches may successfully transfer knowledge and enhance comprehension among learners. The control group's higher mean post-test score than that of the experimental group, however, would indicate that some traditional learning media, like video, might be more appropriate for particular learning environments or student preferences. Important questions are raised by the experimental group's post-test scores showing a substantial difference. Although immersive technology has special benefits like encouraging participation and producing realistic visuals, its effects can differ based on the situation, the level of implementation, and the degree of technology knowledge among the students (Crolla et al., 2024). Potential technological constraints during the intervention or difficulties adjusting to immersive technologies could potentially be the cause of the experimental group's decreased learning gain (Stojšić et al., 2018). These results highlight how crucial it is to match instructional strategies to learning goals and student capabilities (Gaspar et al., 2020). Traditional methods are still quite effective in delivering structured and uncomplicated knowledge, even if immersive technology can be a transformative tool for improving engagement and comprehension in topics that need visual or experience learning.

The higher learning gains observed in the control group compared to the experimental group can be attributed to several possible factors. First, students in the control group were likely more familiar with traditional video-based instruction, which aligned with their previous learning experiences. This familiarity may have allowed them to focus entirely on the content without the added challenge of adapting to new tools, as was the case with the experimental group (Stojšić et al., 2018). Additionally, immersive technology, while engaging, might have introduced a higher cognitive load due to the need for students to navigate and interact with the virtual environment. This could have distracted some students from the core learning objectives. Technical challenges, such as slow loading times or difficulty using immersive tools, may have further disrupted the learning process for the experimental group (Crolla et al., 2024). In contrast, the traditional method in the control group provided a straightforward and structured approach, making it easier for students to process and retain information. Moreover, the exploratory nature of immersive learning requires students to actively piece together knowledge, which might not be as efficient for all learners compared to the direct content delivery often associated with videos. Lastly, the need to adapt to immersive technology, especially for students unfamiliar with such tools, may have diverted attention away from

the material being taught. Together, these factors highlight the importance of considering both the context and readiness of students when implementing new learning technologies.

This study provides significant insights into the effectiveness of immersive technology in teaching, although several limitations must be acknowledged. The sample size was limited, comprising only two classes from one school, perhaps lowering the generalisability of the findings to other educational contexts. Secondly, the study was conducted over only a short period, indicating that the long-term impacts of immersive technology on

student learning and retention were not evaluated. The study concentrated exclusively on science education and the solar system, hence the findings may not be directly relevant to other disciplines or educational settings. Another limitation is the absence of follow-up data, which would facilitate the evaluation of the enduring effects of immersive learning experiences beyond the immediate post-test assessment. At some point despite both the experimental and control groups being instructed by qualified teachers, variations in teaching methodologies or previous familiarity with technology may have impacted the outcomes. Future investigations utilising larger, more heterogeneous samples and extended study periods are essential to better examine the long-term advantages and wider use of immersive technology in education.

Conclusion

This study highlights the potential of immersive technology in education, particularly in enhancing student comprehension of abstract scientific concepts like the solar system. The experimental group, which used immersive learning tools, demonstrated significant improvements in their learning outcomes, underscoring the effectiveness of interactive and visual methods in fostering engagement and comprehension. However, the control group, employing traditional video-based instruction, showed even greater learning gains, suggesting that the familiarity and structured nature of conventional methods can sometimes lead to better immediate results.

These findings suggest that while immersive technology offers unique advantages, its success depends on the context, implementation quality, and readiness of students and educators. Immersive learning is particularly effective for visualizing complex topics, but traditional methods remain highly effective for straightforward content delivery. Future research should explore the long-term impacts of immersive technology, optimize its integration into diverse curricula, and address the challenges that may limit its broader adoption in education. By utilizing the strengths of both approaches, educators can create more effective and inclusive learning environments.

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