Prima Magistra: Jurnal Ilmiah Kependidikan
Volume 7 – Number 2, April 2026, pp 300-307
https://doi.org/10.37478/jpm.v7i2.7191
Open Access: https://e-journal.uniflor.ac.id/index.php/JPM/article/view/7191

ISSN 2721-8112 (print)
ISSN 2722-4899 (online)

TRANSFORMING SCIENCE EDUCATION: EDU-GAME VIRTUAL REALITY AS A CATALYST FOR CONCEPTUAL UNDERSTANDING

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Article History
Received : 06/12/2025
Revised : 12/03/2026
Accepted : 30/03/2026
Keywords:
Conceptual understanding, Science education, Solar system, Virtual reality.

Abstract. An ideal science education requires access to science laboratories. Science laboratories have several access limitations to experiments and practical activities. Virtual Reality (VR) is an effective solution to overcome these challenges. This research and development aims to assess the effectiveness of Edu-Game Virtual Reality in improving students' understanding of concepts. This study is a Research and Development study using the Define, Define, Develop, and Disseminate procedure. This research was conducted on VII-grade students at SMPIT Salman Al Farisi Jogja. The sampling technique used was simple random sampling, and the product trial design was a pretest-posttest control group. The research instruments consisted of conceptual understanding tests and non-tests, in the form of student-response questionnaires for products. Data analysis was carried out using the SPSS program for empirical data, qualitative descriptive methods for validating the learning device instruments, hypothesis testing with the t-test, and effect size analysis using IBM SPSS 25 to assess the effectiveness of the product and improve concept understanding. Based on the analysis that has been done, 1) the product is declared feasible by the expert with a very feasible category; and 2) the use of the Edu-Game Virtual Laboratory Science is significant.

How to Cite: Rahmawati, L., Widowati, A., Wakid, M., & Sari, F. P. (2026). TRANSFORMING SCIENCE EDUCATION: EDU-GAME VIRTUAL REALITY AS A CATALYST FOR CONCEPTUAL UNDERSTANDING. *Prima Magistra: Jurnal Ilmiah Kependidikan*, 7(2), 300-307. https://doi.org/10.37478/jpm.v7i2.7191

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INTRODUCTION

Education in the digital era has revolutionized learning methods by integrating digital technology into the curriculum. This transformation has created a dynamic learning environment, facilitating access to global educational resources (Chiu, 2021). However, adopting education in the digital era, particularly through virtual laboratories, presents challenges that need to be addressed. Adequate technological skills and understanding of the concepts being taught are essential (Sahu et al., 2022). Additionally, digital security and privacy must be considered (Bower et al., 2017), requiring a holistic, sustainable approach to support effective and inclusive learning. The unavailability of science laboratories can lead to several problems in ideal science education (Chen & Tu, 2021). These include limited access to experiments and practical activities, a lack of practical experience, insufficient conceptual understanding, and a lack of laboratory skills training. To overcome these challenges, it is crucial to recognize the significant role that science education plays in shaping students' understanding of scientific concepts (Antonio & Prudente, 2021).

Virtual Reality (VR) has emerged as an effective solution. VR provides simulation experiences that closely resemble reality, allowing students to engage in virtual experiments and practical activities, even without direct access to physical laboratories (Prahanı et al., 2022; Sarioğlu & Giriş, 2020). It enhances conceptual understanding and laboratory skills, providing practical experiences that support effective learning in science. The use of technology, including virtual reality, enables students to learn independently and interactively. This aligns with the concept of "Anytime, Anywhere Learning," which characterizes education in the digital era (Chang et al., 2018).

Moreover, the use of educational games in science learning has shown potential to improve students' conceptual understanding (Srisawasdi & Panjaburee, 2019). The development of an educational virtual laboratory game for science learning can be a valuable tool in enhancing

students' understanding of scientific concepts. Therefore, this research aims to assess the feasibility and effectiveness of VR products in increasing students' understanding of science concepts, providing valuable insights into VR's potential as a tool to enhance science education and improve student learning outcomes.

Although various studies have shown that Virtual Reality (VR) and game-based learning have the potential to improve the quality of science education, several limitations remain that warrant further investigation. A number of studies report that VR can enhance conceptual understanding and student engagement in learning (Srisawasdi & Panjaburee, 2019; Tsirulnikov et al., 2023). On the other hand, the game-based learning approach has also proven effective in improving student motivation and learning outcomes (Chen, 2020; Lu et al., 2020). However, most of these studies still examine the two approaches separately, so the integration of VR and game-based learning into a single learning medium has not been explored in depth.

Furthermore, existing research has generally been conducted at the higher education level or under relatively controlled conditions, so its implementation in real-world learning contexts at the junior high school level remains limited (Chang et al., 2018; Prahani et al., 2022). Yet, at this level, students often struggle to understand abstract scientific concepts, such as material on the solar system. To date, there remains a scarcity of research developing Virtual Reality-based learning media specifically integrated with educational game (edu-game) approaches to support conceptual understanding of such material (Kapici et al., 2019; Sasmito & Sekarsari, 2022).

Therefore, this study was conducted to address this gap by developing a Virtual Reality-based Edu-Game learning medium on the solar system for junior high school students. This study not only focuses on the feasibility of the developed product but also examines its effectiveness in enhancing students' conceptual understanding through an experimental approach, as recommended in previous research on the development of technology-based learning media (Antonio & Prudente, 2021; Chen & Tu, 2021).

The Edu-Game Virtual Science Laboratory is an innovative IT-based learning medium designed to increase conceptual understanding of science materials at the middle school level (Kapici et al., 2019; Kapıcı & Coştu, 2023; Sasmito & Sekarsari, 2022). It harnesses the power of game-based learning, an instructional approach that utilizes games to define and support learning objectives (Chen & Tu, 2021). Supplementing students' learning and enhancing engagement with course material, particularly in physics, chemistry, biology, and earth sciences, provides a comprehensive learning experience. The virtual laboratory simulations are experienced through head-mounted display technology, which has been proven to enhance learning outcomes and increase learner motivation (Tsirulnikov et al., 2023). The effectiveness of game-based approaches in enhancing learning outcomes in practical subjects has also been demonstrated by other virtual laboratory initiatives such as the Virtual Lab by Quantum Flytrap and the virtual experimental laboratory developed at ITMO University (Migdał et al., 2022; Peregudin et al., 2022).

By leveraging the potential of educational games and virtual reality technology, the Edu-Game Virtual Laboratory Science offers a promising avenue for improving science education. Its design fosters active participation, motivation, and the development of essential skills and competencies among learners. The concept of "edutainment" seamlessly blends entertainment and learning, creating an immersive, captivating learning experience (Ristanto et al., 2022). Based on the references and previous research, the Edu-Game Virtual Laboratory Science holds great potential as a transformative tool in science education, addressing the challenges posed by the unavailability of physical laboratories. Through this research, we aim to evaluate the suitability and impact of VR technology on students' understanding of science concepts, providing valuable insights that can enhance students' understanding and make a positive contribution to education.

Based on the background and research gaps outlined above, this study aims to develop a Virtual Reality-based Edu-Game learning medium on the solar system for junior high school students and to assess its feasibility and effectiveness in improving students' conceptual understanding. This study is expected to contribute both theoretically and practically. Theoretically, this study enriches the literature on integrating Virtual Reality technology with an

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educational game approach in science learning. In practice, the results of this study can serve as an alternative to address the limitations of laboratory facilities, while also serving as a reference for teachers in developing more interactive, context-based learning, particularly for abstract topics such as the solar system.

RESEARCH METHODS

This research is Research and Development (4-D) research using development procedures, namely Define, Design, Develop, and Disseminate. Define the stage to define the foundation and plan for developing learning tools. At this stage, a survey was also conducted among 110 science teachers in five districts in the Special Region of Yogyakarta. The Design Stage is the stage of creating initial product specifications, aiming to define the format of the learning tools to be developed. In the development stage, products are made in the form of Student Worksheets, Virtual Reality, and test instruments. The Disseminate stage is the stage of disseminating the learning tools developed. The learning tools were validated by two expert lecturers and four physics teachers. The research subjects were seventh-grade students at SMPIT Salman Al Farisi Jogja for a limited empirical testing. The sampling technique used in this research was simple random sampling, and the product trial design was a pretest-posttest control group. The research instrument consists of tests and non-tests. The test instrument consists of a pretest and a posttest of concept understanding. The non-test instrument is a questionnaire responding to the product. Data analysis was carried out using SPSS for empirical data, qualitative descriptive methods to validate the learning tool instruments, t-tests for hypothesis testing, and effect size analysis in IBM SPSS 25 to assess product effectiveness and increase students' understanding of concepts.

The test validation was done content-wise by consulting with a learning evaluation expert. The research instrument consists of a product validation sheet for materials and media and a conceptual understanding test with the following grid. The lattice of product validation sheets, organized by material, media, and conceptual understanding tests, is shown in Table 1.

Table 1. Grid of Product Validation Sheet

No.	Aspect	Indicator
1.	Software aspect	Effective and efficient in the development and use of science teaching materials, along with VR
		Compatibility (learning media can be installed/run on various existing hardware and software)
		The accuracy of selecting the type of application/software/tool for development
2.	Learning design aspects	Relevance of learning objectives with Learning Outcomes
		Appropriateness of using the inquiry approach
3.	Visual communication aspects	Communicative (in accordance with the message and can be received / in line with the wishes of the target)
		Simple and appealing (colors are not too crowded, right on target as the focus of attention, and images give an attractive impression)
		Visually appealing (design layout, typography, color)
4.	Content or material suitability	Conformity with Learning Outcomes and Flow of Learning Objectives Middle School
		Breadth of material, the arrangement of the material that students find through coherent scientific steps
		The material is easy for students to understand
5.	Language	The language used is easy for learners to understand
		Effectiveness of the language used
		Interactivity and communicativeness of the language and sentences used
6.	Presentation	The use of images, tables, and graphs that are in accordance with the material
7.	Science teaching material model, along with VR	The suitability of activities in science teaching materials, along with VR, with active approach indicators
		Science teaching materials, along with VR, can improve students' high-level thinking skills (HOTS)

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RESULTS AND DISCUSSION

During the design phase, a survey was conducted among 110 science teachers across five districts/cities. The survey results indicated that teachers' understanding of the use of Virtual Reality (VR) in teaching remains relatively low. A total of 11.82% of respondents had never heard of the term VR, 28.18% were aware of it but did not understand it, and 36.36% had a limited understanding. Meanwhile, only 19.09% of teachers had sufficient understanding, and 4.55% had a good understanding and had previously implemented VR in teaching.

In terms of facilities and infrastructure, 23.63% of schools lack devices that support VR use, and 33.63% of teachers have never attended VR training in science education. These findings indicate that the use of VR technology in science education is still suboptimal, both in terms of teacher competence and the availability of facilities. Therefore, the development of VR-based learning media that aligns with on-the-ground needs is required.

Based on the results of this needs analysis, this study developed a Virtual Reality-based learning tool integrated with an educational game (edu-game) approach for teaching the solar system. The developed media is designed to provide an interactive learning experience through the exploration of solar system objects and activities involving the arrangement of planetary orbits. The integration of game elements in this media aims to increase student engagement in learning, so that students do not merely act as recipients of information but are also actively involved in constructing conceptual understanding.

In game-based learning, teachers incorporate games to refresh old concepts or solidify new ones. By leveraging today's students' intimate knowledge of gameplay, teachers can create exciting learning environments that increase student engagement. This research produced a virtual reality about the Solar System. The educational media developed is designed to provide an interactive learning experience and facilitate a more concrete visualization of concepts. It offers an engaging, interactive experience where users can embark on a thrilling journey through space, searching for planets and skillfully arranging them according to their unique orbits. Virtual reality technology allows users to feel as if they are truly part of the solar system, enabling them to explore the vastness of space and interact with the planets firsthand.

This interactive approach enhances student involvement and ignites a genuine interest in learning. Furthermore, this VR design offers students an unparalleled opportunity to develop a comprehensive understanding of orbital concepts. By arranging the planets based on their orbits around the radiant sun, students can grasp the intricate relationships and patterns that govern the celestial bodies in our solar system. The ability to visually observe and interact with the planets in a virtual environment enriches their comprehension and appreciation of the complexity of studying the solar system. The visualizations presented in this VR experience are nothing short of stunning. Students are treated to awe-inspiring, meticulously detailed representations of the planets' surfaces that accurately depict their sizes and orbital movements. The immersive visualizations create a sense of realism, captivating students and enhancing their understanding and interest in the solar system. The incorporation of game-based learning principles adds an extra layer of excitement and challenge to the experience. By transforming the task of finding and organizing planets into engaging missions or timed challenges, students are motivated to actively participate and apply their knowledge. This gamified approach fosters a sense of achievement and encourages students to strive for excellence in understanding orbital concepts. Moreover, integrating VR into game-based education promotes collaboration and healthy competition among students. They can collaborate to locate and arrange the planets correctly, or engage in friendly competition to complete tasks as quickly or accurately as possible. These opportunities for collaboration and competition foster social interaction and cultivate valuable teamwork skills. To support the implementation of the developed media, a systematic approach to virtual reality is required, spanning device setup to user interaction within the virtual environment. The workflow for using this media is shown in Figure 1.

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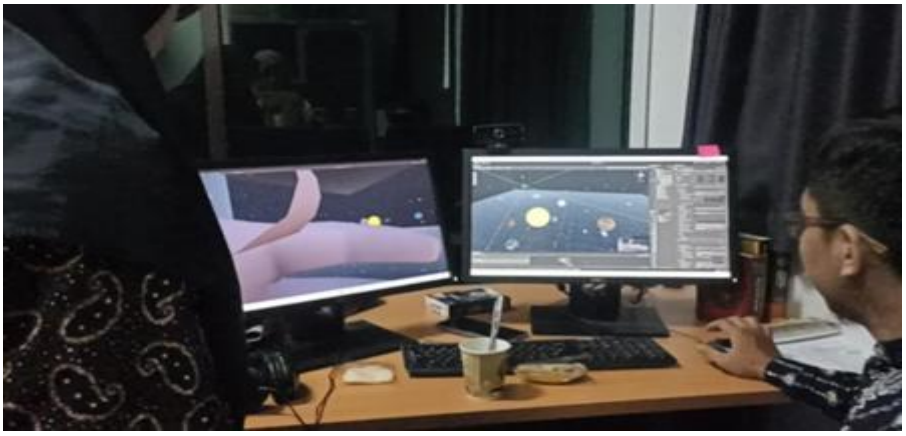


Figure 1. VR set-up process

As for the validation of the VR products, they were validated by two validators: one as a material validator and the other as a teaching material validator. The validator assessment aspects include software, learning design, visual communication, suitability of content or material, language, layout, and the Model of science teaching materials, along with VR, with an average of 3.63. The validation results for Virtual Edu-Game, conducted by material and teaching material experts, are excellent. Experts have confirmed the viability of edu-game-based VR IPA products after their assessment. Their valuable input regarding improvements to content, presentation, and usability has been carefully considered. Regarding content, experts recommend expanding the product to include broader natural science concepts for users to explore. They emphasize the importance of structuring and organizing content to facilitate easy access and understanding of the concepts being taught

Regarding the presentation aspect, experts provide valuable insight into the visual appearance of VR products. They emphasize the importance of realistic and visually captivating representations to immerse and engage users in VR experiences. Additionally, they suggest implementing smoother animations and immersive sound effects to improve the overall user experience. Usability is another key consideration highlighted by experts. They emphasize the need for intuitive and user-friendly interfaces in VR products. Simplifying navigation and control mechanisms in virtual environments is critical to ensuring that users can easily understand and navigate the interface. Additionally, experts suggest incorporating interactive features, such as gesture-based controls or voice recognition, to further increase user engagement in the VR experience. Incorporating the improvements suggested by these experts serves as a valuable guide for developing edu-game-based VR IPA products. By considering expert feedback, products can be refined to offer better experiences, improve students' understanding of concepts, and increase user appeal and engagement in VR environments.

Effectiveness of VR in Improving Concept Understanding

The descriptive analysis results of the pretest-posttest conceptual understanding of solar system material and property inheritance are shown in Table 2.

Table 2. Prerequisite Test Results Solar System Materials

One-Sample Kolmogorov-Smirnov Test			
		Pretest	Posttest
N	Mean	48.8000	63.4667
Normal Parameters[a,b]	Std. Deviation	13.36947	12.99377
Test Statistic		0.189	0.170
Asymp. Sig. (2-tailed)		0.158	0.200

The table shows that the normality test results using Kolmogorov-Smirnov on conceptual understanding data are normally distributed with a significance value (2-tailed) greater than 0.05.

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The results of the homogeneity test indicate that the data have homogeneous variance. The analysis is continued parametrically using the paired t-test. The results of the paired t-test are shown in Table 3.

Table 3. Results of the Paired Sample Test of Solar System Materials

Mean	Std. Deviation	Std. Error Mean	95% Confidence interval of the difference		T	df	Sig. (2-tailed)
			Lower	Upper			
-14.66667	9.75900	2.51976	-20.07102	-9.26231	-5.821	14	0.000

The results of the paired t-test on student conceptual understanding data show a significant difference between before and after teaching using an edu-game-based virtual reality. This is indicated by the significance value (2-tailed) less than 0.05. Table 3 shows that using virtual reality effectively improves students' understanding. This is because the Solar System VR design, with its thrilling planet search and orbit sorting features, seamlessly integrates with game-based education, offering an immersive and effective learning experience. The combination of interactive engagement, improved understanding of concepts, stunning visualizations, challenging gameplay, and opportunities for collaboration and competition makes VR an invaluable tool for deepening students' understanding of the solar system and related scientific concepts.

The use of educational games in science learning has shown potential to improve students' conceptual understanding (Husnaini & Chen, 2019; Srisawasdi & Panjaburee, 2019). This is particularly relevant in the context of online learning, where students may feel disengaged and bored (Ali et al., 2022; Kanık, 2021). The development of multimedia games for Natural Science has been found to be feasible and effective in increasing student motivation (Chen, 2020; Lauc et al., 2020; Lu et al., 2020). These studies collectively suggest that a virtual laboratory game for science learning could be a valuable tool for enhancing students' understanding of scientific concepts.

Learners' Response to VR Products

The questionnaire results show that most students reported that they can learn easily, operate VR without written instructions, save time on learning, access quickly, and feel happy, comfortable, and confident. However, most of them also found the VR difficult to play and still could not find the game menu easily due to its limited availability (specially developed). Most students rated that can learn the material easily through VR SCIVIXPLORER; understand the material presented in VR SCIVIXPLORER easily; obtain specific materials in VR SCIVIXPLORER easily; able to learn and use VR SCIVIXPLORER easily without written instructions; save time in understanding the material with VR SCIVIXPLORER; remember the look of the SCIVIXPLORER VR game; play SCIVIXPLORER VR games if use them again after a few weeks (more than 3 weeks); found various functions integrated with each other in SCIVIXPLORER VR games; can access the features in the SCIVIXPLORER VR Game quickly; find an error on SCIVIXPLORER VR Game; found the Games section complex and not really necessary; can't find the menu looking for in the game; feel comfortable and confident when using the game; be happy with the look of the game design; and think about I will often play using SCIVIXPLORER VR Games.

It shows that the SCIVIXPLORE Virtual Reality product is deemed suitable for use, subject to minor revisions. The development of virtual laboratories for educational games in science education aims to improve students' understanding of concepts. These virtual laboratories provide convenient tools for e-learning and can serve as a replacement for real-life laboratory equipment (Silfiani et al., 2022). They incorporate pedagogical techniques that help students better understand theoretical concepts effectively and joyfully (Antonio & Prudente, 2021). The use of virtual laboratories in the study of automation and control systems enhances learning outcomes (Pandey et al., 2023). Educational software based on game engines, such as Unity 3D, has also been developed to facilitate the study of physics and improve conceptual understanding (Daineko et al., 2018). Overall, the development of edu-game virtual laboratories has the potential to

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enhance student's conceptual understanding in various scientific disciplines.

CONCLUSIONS AND SUGGESTIONS

Edu-Game Virtual Reality products are deemed feasible by experts, with a very feasible rating. Edu-Game Virtual Laboratory Science is an effective learning tool for increasing students' conceptual understanding in natural science. Research shows that the use of the Edu-Game Virtual Laboratory Science significantly increases students' understanding of concepts. With the advantages of interactivity and learning motivation that it provides, Edu-Game Virtual Laboratory Science can be an interesting alternative in the natural science learning process

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