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Enhancing students' interest and conceptual understanding through the Edu Science virtual reality game

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Abstract

A recent study aimed to produce VR products that could be feasibly tested and to determine the effectiveness of these products in improving students' conceptual understanding. This research was conducted using a 4D R&D model. The product was tested with seventh-grade students using a purposive sampling technique, and a pretest-posttest control-group design was used for the product trial. The instruments used consisted of conceptual understanding tests and non-tests in the form of a response questionnaire to the product. The data obtained were analyzed using SPSS. Based on the trials carried out, it was found that Edu-game Science Virtual Reality can improve students' conceptual understanding of the inheritance of traits. Overall, concept application increased, with an N-Gain of 0.197, which is categorized as low. Despite receiving a low category, students' interest in learning science has increased through this Eduscience Virtual Reality Game.

Keywords: Conceptual Understanding, Edu-game, Inheritance of trait, Virtual Reality

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1. INTRODUCTION

Digital technology has revolutionized the education curriculum, making it essential for students to master technology to enhance teaching and learning methods (Bogusevschi et al., 2020; Wohlgenannt et al., 2020; Yates et al., 2021). Governments in the Asia-Pacific region are investing heavily in schools equipped with the latest technology and infrastructure, while also promoting ICT integration and ICT-based instruction (Kim & Lee, 2022). Virtual Reality (VR), as one of these advancements, offers immense potential to revolutionize teaching methods and provide immersive learning opportunities (Bogusevschi et al., 2020). VR is an innovative tool that allows students to experience a digital environment in an immersive way, making it highly applicable to K-12 education (Chiu, 2021; Di Natale et al., 2020; Maas & Hughes, 2020).

In the context of teaching abstract concepts such as the inheritance of traits, traditional learning methods often rely on verbal explanations and textbook descriptions, which make it challenging for students to visualize complex processes. VR-based Edu-Games address these limitations by offering interactive, immersive simulations that allow students to observe genetic combinations, meiosis, and Mendelian patterns in a virtual laboratory (Agbo et al., 2021). Such simulations not only enhance conceptual understanding but also provide hands-on experiences that bridge the gap between theoretical knowledge and practical application (Bogusevschi et al., 2020).

Local studies in Indonesia indicate that 72% of middle school students struggle to grasp the concept of trait inheritance due to its abstract nature and the lack of engaging teaching tools (Sitompul et al., 2023). Moreover, data from the Ministry of Education and Culture (2023) indicate that Indonesian students often perform below international standards in biology, particularly in topics requiring higher-order thinking skills, such as genetics. This underscores the need for innovative solutions like VR Edu-Games to foster deeper conceptual understanding and improve science education outcomes. By providing an engaging and interactive platform, VR Edu-Games help students overcome learning difficulties and improve their academic performance.

In addition to improving conceptual understanding, VR technology offers several advantages. For instance, VR allows students to conduct virtual experiments safely and cost-effectively (Pamungkas et al., 2020). These experiments can be repeated multiple times without additional material costs, enabling students to explore various scenarios at their convenience. The immersive environment also enhances problem-solving abilities, computer literacy, and practical skills essential for lifelong learning (Agbo et al., 2021). Furthermore, VR encourages collaboration and communication between students and teachers, fostering a dynamic, interactive learning environment (Bogusevschi et al., 2020).

The integration of VR-based Edu-Games into the education system aligns with global and regional priorities to modernize education and foster innovation (Widodo et al., 2023). As governments in Southeast Asia aim to raise their educational systems to international standards, VR technology is a promising tool for achieving these goals. By providing students with engaging and effective learning experiences, VR Edu-Games can enhance motivation, engagement, and conceptual understanding, addressing the gaps in traditional teaching methods (Laine & Lindberg, 2020).

This research highlights the significant role of VR-based Edu-Games in addressing the challenges faced by traditional learning methods. By combining immersive technology with sound pedagogical strategies, VR enables students to connect abstract concepts with tangible experiences, paving the way for a more

inclusive and effective science education. It also emphasizes the importance of teacher training, curriculum alignment, and infrastructure development to ensure the successful implementation of VR in classrooms.

By fostering active participation, motivation, and essential skills, VR Edu-Games offer an innovative solution to enhance science education. This approach not only improves academic performance but also prepares students to face future challenges in an increasingly digital world (Rojas-Sánchez et al., 2023). The findings of this study contribute meaningfully to advancing educational technology, particularly in Indonesia and Southeast Asia, by demonstrating how VR can revolutionize the teaching and learning of abstract scientific concepts.

Edu-games and virtual reality technology have the potential to significantly improve science education. By fostering active participation, motivation, and the development of essential skills and competencies, edutainment creates an immersive, captivating learning experience. The concept of "edutainment" blends entertainment and learning, offering a promising avenue for improving science education (Laine & Lindberg, 2020). Our research aims to assess the effectiveness and impact of Virtual Reality (VR) technology in enhancing students' comprehension of scientific concepts. To this end, this study seeks to answer the following research questions, (1) How effective are VR-based Edu-Games in improving students' conceptual understanding of the inheritance of traits?, (2) What are the perceptions of students and teachers regarding the feasibility and usability of VR-based Edu-Games in the classroom?, and (3) How does the use of Edu-Games impact students' motivation and engagement in science education?. By addressing these questions, this research aims to make meaningful contributions to the field of science education, particularly by integrating innovative technologies, such as VR, into the teaching of abstract scientific concepts.

2. METHOD AND MATERIALS

2.1. Participants

The population in this study was students from SMPIT Salman Al Farisi in Yogyakarta, Indonesia. The sample in this study was seventh-grade students. The selection process used purposive sampling to ensure the sample represented students with varying levels of technological literacy and prior experience with virtual reality (VR)-based learning. This choice was based on their curriculum alignment with the instructional material covered in the study and their accessibility for both pre-test and post-test assessments. The sample size was determined to ensure statistical reliability, considering both the experimental and control groups for comparative analysis, thereby enabling a robust evaluation of the developed VR learning tool.

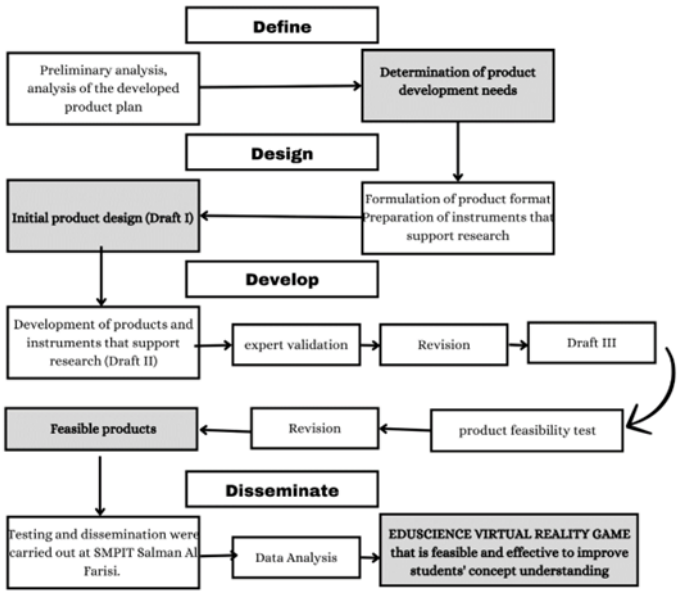
2.2.Research Design and Procedures

This study employed a Research and Development (R&D) methodology using the 4D model, which comprises four stages: Define, Design, Develop, and Disseminate. The 4D model was chosen for its structured approach to guiding educational product development, ensuring that the VR-based learning tool was effectively conceptualized, designed, validated, and tested before broader dissemination. Recent studies support the use of this model in educational technology development, highlighting its effectiveness in creating structured, iterative improvements (Thiagarajan et al., 1974). The research was conducted over eight months, from the initial needs analysis to the final assessment of students' conceptual understanding. In the Define stage, researchers conducted field observations and interviews with science teachers to identify key challenges in teaching inheritance concepts, which informed the essential features required for

the VR Edu-Game. The Design stage involved developing the initial specifications of the VR-based learning tool, determining necessary software and hardware components, designing virtual content, and mapping instructional materials. The output of this stage included a preliminary draft of the VR Edu-Game and its accompanying worksheets. The Develop stage involved refining and validating the VR learning tool through assessments from two expert lecturers and four physics teachers, focusing on content accuracy, usability, and pedagogical alignment. Multiple revision cycles ensured product improvement, and limited trials with middle school students evaluated feasibility. Finally, in the Dissemination stage, the effectiveness of the VR Edu-Game was assessed based on students' conceptual understanding, with additional efforts to introduce the product to educators and stakeholders in science education. The 4D design used is presented in Figure 1.

Figure 1

Flowchart 4-D models.



2.3.Instrument

The research instruments included both test-based and non-test-based measures. To evaluate students' conceptual understanding, a pre-test and a post-test were administered, each comprising 25 multiple-choice questions adapted from established assessment frameworks and reviewed by subject-matter experts to ensure validity. Additionally, a questionnaire was used to collect students' responses regarding their experience with the VR Edu-Game. The questionnaire consisted of 15 statements rated on a Likert scale, addressing ease of use, engagement, perceived learning effectiveness, and overall satisfaction. Validity and reliability tests using Cronbach's alpha ensured consistent responses, supporting the robustness of the data collection process (Ali et al., 2022).

2.4.Data Analysis

Data analysis incorporated both descriptive and inferential statistical techniques. The effectiveness of the VR Edu-Game was measured using the N-Gain score to assess improvements in students' conceptual understanding. At the same time, a paired t-test was conducted to determine the statistical significance of pre-test and post-test differences. Recent studies suggest that additional regression analysis can offer deeper insights into the relationship between students' technological literacy and their conceptual understanding. Consequently, regression analysis was performed to explore these factors further. All statistical analyses were conducted using IBM SPSS 25 to ensure reliable and comprehensive interpretations of the data. This multifaceted approach provided a detailed evaluation of the VR-based learning tool's effectiveness, reinforcing its potential impact on science education.

3. RESULTS

This research is a type of research and development, following the 4D model comprising define, design, develop, and disseminate stages.

3.1.Define Stage

The definition stage led to the identification of product development needs. Based on observations and interviews with science teachers at SMPIT Salman Yogyakarta, it was found that the use of science laboratories was suboptimal. This is due to limited facilities: the school does not yet have an adequate science laboratory or sufficient tools and materials, so the practicum cannot be carried out optimally. As a result, learning focuses more on theory than practice. In addition, the use of Virtual Reality (VR) technology in science learning has never been applied. This obstacle stems from a lack of teachers' knowledge and skills in integrating VR technology into the curriculum, as well as limited resources to support its implementation. This condition results in students not receiving an interactive, in-depth learning experience that should be provided through a hands-on practicum or VR simulation. To overcome this problem, efforts are needed to improve laboratory facilities, train teachers to use VR technology, and integrate it into the science learning process.

3.2.Design Stage

In the design stage, the initial product design (Draft I) was produced. At the stage of design, researchers determine the basic competencies (KD) and the material to be used, namely, inheritance of traits. Based on the material that has been determined, an outline and a concept map are needed. In addition, the developer compiled worksheets and usage manuals, which are collectively known as the SCIVIXPLORER manual book.

Figure 2

Worksheet and manual book at the design stage.

3.3.Develop Stage

The product, developed as an Edu science virtual reality game on the inheritance of traits, is assessed/validated by two experts: science material experts and media experts. Before testing the Edu science Virtual Reality Game, validation was conducted by two experts (media and inheritance material specialists). The validation results are presented in Table 1.

Table 1

The result validation

No.	Aspect	Result %	Category
1	software aspect	100%	very valid
2	Learning Design Aspects	100%	very valid
3	Visual Communication Aspect	100%	very valid
4	Content or material suitability	87.5%	very valid
5	Language	83.25%	very valid
6	Layout	100%	very valid
7	Science teaching material model, along with VR	100%	very valid
average		**95.75%**	**very valid**

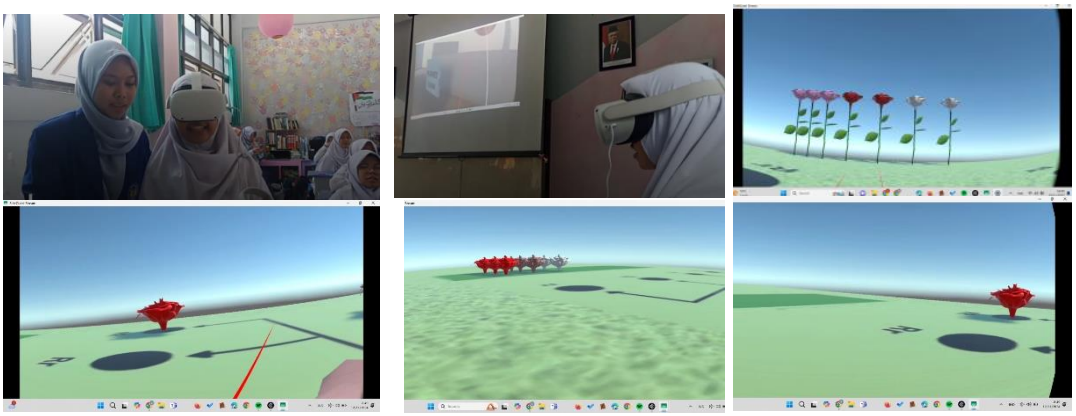
Based on Table 1, the Edu Science Virtual Reality Game was considered suitable for testing, receiving a 95.75% rating in the very valid category. The Edu-game was then tested on seventh-grade students at SMPIT Salman Al Farisi in Yogyakarta, Indonesia.

3.4. Disseminate Stage

At the dissemination stage, the Edu Science Virtual Reality Game is developed and found to be feasible and effective in improving students' conceptual understanding at SMPIT Salman Al Farisi in Yogyakarta, Indonesia. A virtual reality educational game is being developed to teach the principles of inheritance. The aim of this game is to make learning more engaging for students. By using the concepts of Mendel's Law I and Mendel's Law II in animals and plants, the game will help students to better understand these concepts. The game will be played in groups using virtual reality, and students will conduct experiments related to Mendel's Laws according to the instructions in the student worksheet.

Figure 3

Trial VR Edu science games.



The prerequisite test results indicated that the concept understanding data were normally distributed and homogeneous, as shown in Table 2.

Table 2

One-Sample Kolmogorov-Smirnov

One-Sample Kolmogorov-Smirnov Test			
		Pretest	Posttest
Normal parameters	Mean	43.6923	55.3846
	Std. deviation	11.13092	8.46107
Most extreme differences	Absolute	0.157	0.191
	Positive	0.104	0.139
	Negative	-0.157	-0.191
Test statistic		0.157	0.191
Asymp. Sig. (2-tailed)		0.200	0.200

The analysis proceeded parametrically using a paired t-test, as the prerequisite test indicated normality and homogeneity. The mean pretest score for conceptual understanding was 43.692, while the mean posttest score was 55.38. The N-Gain analysis showed a value increase of 0.197. Although this increase is considered low, the use of virtual reality-based Edu games led to a statistically significant improvement in students' conceptual understanding (p = 0.000).

In alignment with constructivist learning theory, VR technology provides a platform for active learning by enabling students to explore, experiment, and discover within an interactive environment. Through immersive learning, students actively construct knowledge rather than passively receiving information (Su et al., 2022; Yu et al., 2021; Zeng et al., 2020). Furthermore, the data were analyzed using a paired t-test as shown in Table 3.

Table 3

Paired Sample test

Mean	Std. Deviation	Std. Error mean	T	Df	Sig. (2-tailed)
-14.66667	9.75900	2.51976	-5.821	14	0.000

According to the paired T-test results, using the Edu-game virtual reality inheritance material has a significant value of 0.000. This indicates that Edu-game has a positive impact on students' conceptual comprehension. Using an Edu-game makes learning more enjoyable and may help bridge the gap between abstract and scientific concepts (Zeng et al., 2020). Furthermore, the data were analyzed in detail on each indicator of concept understanding that has been determined, such as 1) restate a definition; 2) identify objects according to characteristics; and 3) apply the concept, as shown in Figure 4.

Figure 4

Comparison of pretest and posttest means on each indicator of concept understanding.

According to Figure 4, the restate-a-concept indicator increased from 14.85 to 20.85. Based on these two values, the N-Gain is 0.664, which falls in the moderate category. The Edu Science Virtual Reality Game can help students in restating a concept. This product makes it easier for junior high school pupils to understand the idea of the inheritance of abstract qualities, particularly during the crossover process. The N-Gain value

of these two values was 0.068. However, this Edu Science Virtual Reality Game has helped kids become more interested in learning science, even though it received a low category. Since applying a concept is the most challenging step in the concept comprehension process, students must practice the indication frequently to develop the ability to apply concepts to situations and daily life. Nonetheless, it is important to emphasize that acquiring factual or procedural knowledge is the first step in conceptual comprehension. The literature makes it clear that, for students to develop conceptual understanding, they need a solid foundation in facts and procedures (Mills, 2016).

The results of the questionnaire indicate that most students reported being able to learn easily, operate VR technology without written instructions, save time while learning, access information quickly, and feel happy, comfortable, and confident while using it. However, most found it difficult to play the games in VR and had trouble finding the game menu due to their limited availability (as they were developed specifically). Finally, most students rated their VR experience positively.

Table 4

Student response score average

No.	Statements	Score
1	I can learn the material easily through VR SCIVIXPLORER	4.30
2	I can understand the material presented in VR SCIVIXPLORER easily	4.30
3	I obtain specific materials in VR SCIVIXPLORER easily	4.30
4	I was able to learn and use VR SCIVIXPLORER easily without written instructions	4.20
5	I save time in understanding the material with VR SCIVIXPLORER	4.30
6	I can remember the look of the SCIVIXPLORER VR game	4.40
7	I can play SCIVIXPLORER VR games if I use them again after a few weeks (more than 3 weeks)	4.20
8	I found various functions integrated with each other in SCIVIXPLORER VR games	4.50
9	I can access the features in the SCIVIXPLORER VR Game quickly	4.30
10	I can find an error in the SCIVIXPLORER VR Game	3.70
11	I found the Games section complex and not necessary	3.80
12	I can't find the menu looking for in the game	4.00
13	I feel comfortable and confident when using the game	4.30
14	I am happy with the look of the game design	4.30
15	I think that I will often play using SCIVIXPLORER VR Games	4.20
Average score		4.21

Table 4 indicates that the SCIVIXPLORE Virtual Reality product has been deemed appropriate for use, with some minor revisions required. Findings from interviews with multiple students about their use of the product can help clarify this result. Student 1 reported feeling very excited about learning using virtual reality after using it. He felt content after playing VR and found it thrilling. He claims that playing VR games is enjoyable and that they challenge him. He is eager to use virtual reality (VR) to learn science, and he believes the experience will improve with more challenging content.

4. DISCUSSION

A VR design focused on the inheritance of monohybrid and dihybrid traits through gamete crossing images offers students an interactive, immersive learning experience. Students actively participate in a VR simulation of the genetic inheritance process at the molecular level. By leveraging VR, students can visually comprehend the inheritance of traits through gamete crossing. They select gametes to cross and observe the resulting offspring through visual representations. Incorporating game elements enables students to actively engage in the learning process, enhancing their understanding of key genetic concepts such as alleles, genotypes, phenotypes, probabilities, and inheritance ratios. VR features, including three-dimensional visualization, animations, and interactive components, create an engaging educational environment. This immersive experience significantly enhances their grasp of genetics, reinforcing abstract concepts through interactive, hands-on learning (Marougkas et al., 2023; Scavarelli et al., 2021).

The use of educational virtual reality games aligns with the constructivist learning paradigm. Constructivist learning experiences are enabled by VR technology, which allows students to engage in interactive environments that promote experimentation, exploration, and discovery (Song et al., 2023). Students can actively expand their knowledge in a virtual setting by utilizing virtual reality (VR). Additionally, students engage in active learning by working through issues in educational games (Marougkas et al., 2023; Scavarelli et al., 2021; Soliman et al., 2021).

Educational games that incorporate virtual reality technology offer numerous benefits, particularly in the Asia Pacific region. These benefits include boosting student engagement and motivation to learn, enabling students to learn independently by reinforcing their knowledge through virtual reality media, and promoting problem-solving skills through collaboration and communication among multiple learners in the same virtual space (Su et al., 2022; Yu et al., 2021).

According to student 2's interviews, learning using virtual reality is enjoyable. He claims he feels as if he is in another universe when he plays with virtual reality. Although student 2 dislikes playing games, he is intrigued by the obstacles in virtual reality and finds them challenging. The development of an Edu-game in science education aims to enhance students' understanding of key concepts. These games incorporate pedagogical techniques that enable students to understand theoretical concepts in a fun and effective manner (Hanif, 2020; Nguyen & Pham, 2020). Virtual reality is an effective tool for enhancing learning outcomes in the study of automation and control systems (Chang et al., 2018; Kaplan et al., 2021; Soliman et al., 2021). Developing Edu-game-based virtual reality can enhance students' understanding of scientific concepts across disciplines.

5. CONCLUSION

Virtual reality combined with educational games can be a useful tool for teaching about inheritance in science. Where this abstract material gets a good response, familiarity will have a significant impact. This

method has been shown to significantly improve students' understanding of concepts. However, when it comes to trait inheritance, the increase in conceptual understanding remains in the low range, with an N-Gain of 0.197. Nevertheless, students have responded positively to the application of virtual reality-based educational games. This type of learning aligns with constructivist learning theory, where students actively learn and build knowledge in a virtual environment. Educational games can simplify abstract material on inheritance, making it more understandable and interesting for students. The development of educational games can benefit students not only in the Asia Pacific region but also globally.

6. RECOMMENDATION AND FUTURE DIRECTIONS

Despite the positive impact of VR on conceptual understanding, this study had limitations, particularly the small sample size, which may restrict the generalizability of the findings. Future studies should expand the sample to include students from different schools and grade levels to more broadly validate the effectiveness of VR-based learning.

Another limitation was the complexity of the VR interface, which some students found difficult to navigate. To address this, future iterations should include user-friendly interfaces and tutorials. Additionally, teacher training programs should be developed to help teachers effectively integrate VR into their teaching strategies. To enhance accessibility, future research should focus on developing VR applications compatible with a range of devices, including mobile phones and tablets, to enable broader implementation in schools with limited technological resources.

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