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The Effect of Virtual Reality (VR) Learning Media on Enhancing Critical Thinking Skills in Science Subjects among 4th Grade Students at an Integrated Islamic Elementary School

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ABSTRACT

Due to repetitive, teacher-centered education, which makes students passive and less involved in the learning process, SDIT Al-Ishlah Sudimampir students' critical thinking abilities in scientific classes are low. Virtual reality (VR) media is thought to be able to offer a stimulating educational experience and can improve 21st-century abilities, especially critical thinking. This study intends to: (1) investigate the use of Virtual Reality (VR) learning materials in Natural Science (IPA) courses for fourth-grade students at SDIT Al-Ishlah Sudimampir; (2) evaluate the enhancement of critical thinking abilities among fourth-grade science learners following the use of VR-based learning materials; and (3) ascertain if employing VR learning materials has a greater influence on fourth-grade pupils at SDIT Al-Ishlah Sudimampir than using traditional media (PowerPoint). This study used a Nonequivalent Control Group Design using a quantitative methodology. Fifty-two students made up the sample, which was split into two groups: a control group (25 students using PowerPoint) and an experimental group (27 students using VR). Pre-tests, post-tests, and observation sheets were used to gather data, which were then analyzed using both descriptive and inferential statistical techniques. The study's findings demonstrate that: (1) the use of virtual reality learning materials was effective, as demonstrated by observational data showing that student participation in the experimental class and the learning implementation both achieved an exceptional category (100%); (2) After using VR learning materials, students' critical thinking abilities significantly improved, as evidenced by the experimental group's average pre-test score of 51.85, which rose to 86.67 in the post-test; and (3) the Independent Samples T-test showed a significant difference between the two groups, with a Sig. (2-tailed) value of 0.000 (< 0.05). The experimental group's average N-Gain score was 0.756 (high category), which was significantly higher than the control group's 0.519 (medium category). These results showed that the learning medium had a substantial impact on students' critical thinking abilities, leading to the rejection of the null hypothesis (H_0) and the acceptance of the alternative hypothesis (H_1). Thus, it can be said that using Virtual Reality (VR) learning materials significantly improves students' capacity for critical thought.

KEYWORD : *virtual reality; critical thinking; ilmu pengetahuan alam; elementary school*

ABSTRAK

Pendidikan yang bersifat repetitif dan berpusat pada guru menyebabkan siswa menjadi pasif dan kurang terlibat dalam pembelajaran, sehingga kemampuan berpikir siswa di SDIT Al-Ishlah Sudimampir dalam mata pelajaran sains menjadi rendah. Media *virtual reality* (VR) dianggap mampu menawarkan pengalaman pendidikan yang merangsang dan dapat meningkatkan kemampuan abad ke-21, khususnya berpikir kritis. Penelitian ini bertujuan untuk: (1) menyelidiki penggunaan media pembelajaran *virtual reality* (VR) dalam mata kuliah Ilmu Pengetahuan Alam (IPA) untuk siswa kelas

empat di SDIT Al-Ishlah Sudimampir; (2) mengevaluasi peningkatkan kemampuan berpikir kritis pada mata pelajaran sains kelas 4 setelah menggunakan media pembelajaran *Virtual Reality* (VR); dan (3) memastikan apakah penggunaan materi pembelajaran VR memiliki pengaruh yang lebih besar pada siswa kelas empat di SDIT Al-Ishlah Sudimampir daripada menggunakan media tradisional (*Power Point*). Penelitian ini menggunakan Nonequivalent *Control Group Design* dengan menggunakan metodologi kuantitatif. Sebanyak 52 siswa menjadi sampel, yang dibagi menjadi dua kelompok: kelompok kontrol (25 siswa menggunakan PowerPoint) dan kelompok eksperimen (27 siswa menggunakan VR). Intrumen penelitian yang digunakan adalah menggunakan teknik statistik deskriptif, uji normalitas, uji homogenitas, uji *independent sample t-test*, dan uji n-gain. Temuan penelitian menunjukkan bahwa: (1) penggunaan media pembelajaran *virtual reality* efektif, sebagaimana dibuktikan oleh data observasi yang menunjukkan bahwa partisipasi siswa di kelas eksperimen dan implementasi pembelajaran keduanya mencapai kategori luar biasa (100%); (2) Setelah menggunakan materi pembelajaran VR, kemampuan berpikir kritis siswa meningkat secara signifikan, sebagaimana dibuktikan oleh skor pra-tes rata-rata kelompok eksperimen sebesar 51,85, yang naik menjadi 86,67 pada pasca-tes; dan (3) Uji-T Sampel Independen menunjukkan perbedaan yang signifikan antara kedua kelompok, dengan nilai Sig. (2-tailed) sebesar 0,000 (< 0,05). Nilai rata-rata N-Gain kelompok eksperimen adalah 0,756 (kategori tinggi), yang secara signifikan lebih tinggi daripada kelompok kontrol yang hanya 0,519 (kategori sedang). Hasil ini menunjukkan bahwa media pembelajaran memiliki dampak yang substansial terhadap kemampuan berpikir kritis siswa, yang mengarah pada penolakan hipotesis nol (H_0) dan penerimaan hipotesis alternatif (H_1). Dengan demikian, dapat dikatakan bahwa penggunaan media pembelajaran *virtual reality* (VR) secara signifikan meningkatkan kapasitas siswa untuk berpikir kritis.

KATA KUNCI : *virtual reality; berpikir kritis; ilmu pengetahun alam; sekolah dasar*

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INTRODUCTION

21st-century abilities are necessary in the digital age to effectively tackle global issues. The six Cs critical thinking, teamwork, communication, creativity, cultural sensitivity, and connectedness are examples of these soft talents (1). The 6Cs stand for cooperation, communication, creativity, cultural sensitivity, and connectedness (1). Among these, critical thinking is an essential ability that has to be cultivated during the educational process. To make wise decisions and judgments, it entails recognizing, evaluating, and resolving issues in a creative and rational manner. Critical thinking is a higher-order thinking talent that is crucial to science education. Science education places a strong emphasis on investigating natural phenomena not only imparting knowledge of facts, ideas, or principles, but also encouraging inquiry and exploration (2).

The intellectual process of critical thinking includes the capacity to recognize and assess data in order to provide precise responses and to conduct methodical, in-depth issue analysis (3). In order to solve difficulties and make wise judgments in their daily lives, students must master this ability. They must be able to collect and evaluate pertinent data, weigh several potential options, and select the best course of action for addressing problems (4). Without critical

thinking, children may passively absorb information without questioning its veracity or considering the best options, which reduces the effectiveness of the problem-solving process.

According to the 2022 PISA findings, Indonesian students' critical thinking abilities are still comparatively weak. With a ranking of 69th out of 80 participating nations, Indonesia improved by 5 to 6 spots from the 2018 evaluation. The average reading, math, and science scores of Indonesian pupils actually decreased in spite of the higher ranking (5). The effect of the COVID-19 epidemic, which left many nations, including Indonesia, unable to deal with its aftermath, was one of the causes that contributed to this drop. Additionally, the results of the Minimum Competency Assessment (AKM), which show that the majority of students still have difficulty understanding, analyzing, and evaluating material in-depth, also demonstrate the low level of students' critical thinking abilities. Azizia claims that pupils struggle to answer PISA questions about relationships and change, especially when it comes to connecting mathematical models to real-world issues and deriving logical inferences from their answers (6). This demonstrates the pressing need for a more creative teaching methodology that prioritizes the growth of critical thinking abilities in order to raise the standard of education in Indonesia. In order to pique students' interest in learning, interactive media must be incorporated into the curriculum. This can indirectly improve students' critical thinking skills. Therefore, to increase students' interest in learning and to support the growth of their critical thinking, creativity, and problem-solving skills, interactive, technology-based teaching strategies like experiments and exploratory activities are required (7). Thus, interactive, technology-based learning approaches such as experiments and exploratory activities—are essential for enhancing students' interest in learning and for developing their critical thinking skills, creativity, and problem-solving abilities.

Students' development of critical thinking abilities is greatly influenced by the teacher's participation in the learning process. It is desirable for the learning process to automatically lead to student participation in knowledge construction and comprehension of learning ideas. In actuality, though, the process frequently stays mostly teacher-centered. Choosing relevant educational materials that promote educational reform and foster creativity in scientific education is one way to deal with this problem (8). Therefore, students' conceptual development in scientific courses is greatly influenced by the learning medium that teachers employ to present the topic (9).

The creation of creative and interactive learning materials is the result of a substantial shift in the development of educational technology. Virtual reality (VR) is one such technology that has drawn interest from educators (10). Through investigation and practical experiences, this technology enables students to actively participate in the learning process in addition to passively absorbing knowledge. Because of its special benefits, using virtual reality (VR) as a teaching tool might increase students' motivation for learning (11). This technology

makes complicated material easier to learn by allowing students to explore abstract ideas in a more realistic and engaging way. Because of interactive simulations and 3D visualization, To understand processes or phenomena like the solar system, the structure of the human body, or chemical reactions, students no longer have to depend just on still photographs from textbooks (12). Virtual Reality (VR) has the capability to provide immersive and contextual learning experiences, facilitate critical thinking through interactive simulations, and stimulate students' critical thought processes by engaging them in realistic and meaningful scenarios. Thus, by making the learning process more dynamic and less repetitive, virtual reality (VR) increases student motivation by making learning more engaging and pleasurable.

Based on the research conducted by Dhea Annisa and Yunus Abidin (2024) entitled "Needs Analysis for the Development of Virtual Reality Media on the Digestive System to Improve Critical Thinking of Fifth Grade Elementary Students," it was shown that Virtual Reality media can stimulate students' critical thinking skills, and that the learning process becomes more meaningful as students feel as if they are actually present in the visualized environment. The study concluded that there is a current need for teachers to utilize digital learning media for teaching the digestive system, incorporating technological innovations such as Virtual Reality. The similarity between their research and the present study lies in the use of Virtual Reality (VR) as a learning medium to enhance student engagement and learning outcomes in science education at the elementary school level. However, the difference in this study is the integration of Virtual Reality media with the Problem-Based Learning (PBL) model. This study offers novelty through the integration of the Problem-Based Learning model assisted by Virtual Reality as an innovative approach to enhance students' critical thinking skills in science learning, which has specifically not been widely explored in previous research.

Moreover, as stated by Attalina (2024) (13) The benefits of this VR learning material are found in its use, which provides a more captivating educational experience and displays data in a more appealing and realistic manner. As the learning process grows more engaging and demanding, virtual reality media may help increase students' motivation and interest in studying. Through the use of virtual reality (VR) media, students may investigate and engage with things, locations, or ideas that are hard to reach in real life, greatly expanding their knowledge base.

This study aims to improve students' understanding of the subject matter by using Virtual Reality (VR) as a learning medium. The use of Virtual Reality (VR) in learning can help students grasp the material more easily and deeply. In addition, this study seeks to enhance students' critical thinking skills by designing learning activities that encourage the to analyze information, evaluate arguments, and draw their own conclusions. It may be inferred from the difficulties raised that technology-based learning resources, including virtual reality

(VR), can be used to overcome these obstacles. It is anticipated that VR media would be successful in removing present barriers to learning, especially when it comes to improving students' critical thinking abilities.

This study offers novelty through the integration of the Problem-Based Learning model assisted by Virtual Reality as an innovative approach to enhance students' critical thinking skills in science learning, which has specifically not been widely explored in previous research.

RESEARCH METHOD

This study uses a nonequivalent control group design and a quantitative methodology. Both the experimental and control groups are chosen without random assignment in this design, which uses a quasi-experimental methodology. Pre- and post-tests are administered to both groups, but only the experimental group is given the therapy (14). A pre-test was administered to both classes before to the therapy in order to gauge the students' preliminary critical thinking skills. Virtual Reality (VR) learning materials were then employed to treat the experimental class, whereas PowerPoint and traditional learning materials were used in the control group. A post-test was administered to both groups following the learning sessions in order to assess their critical thinking abilities and identify any notable distinctions between the VR and PowerPoint media groups.

All of the students of SDIT Al-Ishlah Sudimampir made up the study's population. The sample was split into two groups: the experimental group (class 4B, which included 27 students) received treatment using virtual reality learning materials during the learning process, and the control group (class 4A, which included 25 students) did not.

This study included testing, documentation, and observation as data gathering methods. Validity testing is done to make sure that the data collected accurately reflects the real conditions of the research subjects. Reliability testing is done to make sure that the instruments yield consistent results when used repeatedly, which guarantees that the data obtained are reliable and valid. The result of the reliability testing are as follows.

Table 1. Instrument reliability test results

Reliability Statistics	
Cronbach's Alpha	**N of Items**
0.818	5

Table 1, presents the results of the instrument reliability test using Cronbach's Alpha coefficient, which yielded a value of 0.818 for 5 items. According to the interpretation category by Taber (2018), this value falls within the range of 0.80 – 0.89, which is classified as "good." This indicates that the instrument has high internal consistency and is reliable for use in the research data collection process.

While homogeneity testing seeks to evaluate if the variances across various data groups are equal, normality testing determines whether the data come from a population that is regularly distributed. Lastly, an Independent Sample T-Test is used for hypothesis testing in order to ascertain

whether the independent variable significantly affects the dependent variable (15). The efficacy of the learning process in raising students' learning outcomes is evaluated using the N-Gain test.

RESULTS AND DISCUSSION

Research Findings

Using an observation sheet, the researcher gathered observational data on the use of virtual reality (VR) learning materials. The purpose of this observation sheet was to track how teachers were using VR instructional resources.

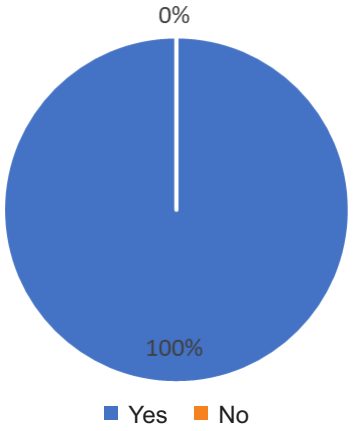

Figure 1. Result of Observation Sheet

The use of virtual reality (VR) media had a 100% success rate, which is classified as "excellent," according to the data shown in the graph above. This shows that every step of the VR media learning process was completed as effectively as possible and in accordance with the lesson plan. In the initial observation stage, only two classroom teachers were involved to gain a preliminary understanding of the teaching process and the media needs relevant to the students' characteristics.

The distribution of students' critical thinking test scores before and after the use of virtual reality (VR) learning materials is shown by the findings of the descriptive statistical analysis. Pre-test and post-test results from the experimental class, which employed virtual reality media to enhance learning, are among the data collected.

The **Table 1**, show that the average pre-test score was 52,00, while the average post-test score rose to 76,40 a considerable improvement. Pre-test scores ranged from a minimum of 30 to a maximum of 75. All students demonstrated progress after using the virtual reality learning materials, as evidenced by the fact that the minimum post-test score increased to 75 and the maximum to 100. At the start of the learning process, students' results varied quite a bit, as seen by the pre-test standard deviation of 12.09. On the other hand, the post-test standard deviation dropped to 9.09, indicating that students' gains in critical thinking abilities

Table 2. Descriptive statistics of pre-test and post-test results control and experimental classes

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Pretest_Kontrol	25	30	75	52	12.07615
Posttest_Kontrol	25	65	90	76.4	8.35663
Pretest_Eksperimen	27	30	75	51.2963	12.90443
Posttest_Eksperimen	27	75	100	86.6667	9.09353
Valid N (listwise)	25				

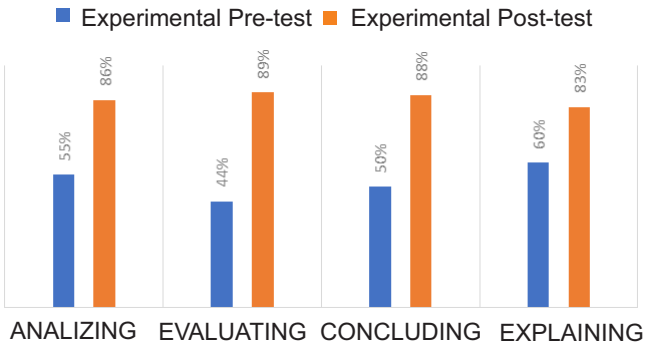

Figure 2. Results per Indicator of Critical Thinking Ability

were dispersed more fairly following the use of virtual reality media.

By determining the proportion of achievement for each indication using the experimental group's pre-test and post-test findings, a descriptive study of critical thinking abilities was carried out.

The critical thinking skill assessed in this study were based on four indicators as proposed by Facione; analyzingm evaluating, explaining, and concluding. Each test item in the pre-test and post-test was constructed to reflect one of these indicators. This allowed the researcher to examine students' performance across each specific of critical thinking. The experimental class's percentages increased significantly from the pre-test to the post-test, according to the examination of each critical thinking skill indicator. The pre-test 'analyzing' indication was 55%, while the post-test 'analyzing' indicator was 86%. From 44% to 89%, the 'evaluating' sign rose. Furthermore, the 'explaining' indication increased from 50% to 88%, while the 'concluding' indicator improved from 60% to 83%.

Table 3. Result test of normality

Tests of Normality			
	Kolmogorov-Smirnov[a]		
	Statistic	df	Sig.
pretest_kontrol	0.126	25	0.200*
postest_kontrol	0.154	25	0.131
pretest_eksperimen	0.147	25	0.112
postest_eksperimen	0.171	25	0.068

According to the findings of this study's normality test, the experimental group's pre-test and post-test significance (Sig.) values were 0.112 and 0.068, respectively. The data are normally distributed as both values are higher than the significance level of 0.05. Likewise, the pre-

Table 4. Result tests of homogeneity of variances

Tests of Homogeneity of Variances					
		Levene Statistic	df1	df2	Sig.
pretes_postes_eksperimen_pretes_postes_kontrol	Based on Mean	1.349	3	100	0.263
	Based on Median	0.881	3	100	0.454
	Based on Median and with adjusted df	0.881	3	85.608	0.454
	Based on trimmed mean	1.335	3	100	0.267

test and post-test significant scores for the control group were 0.200 and 0.131, respectively, indicating a normal distribution. In order to determine if the variances between groups are homogenous, the study may now go on to the homogeneity test as it can be determined that the data from both groups meet the assumption of normalcy.

The pre-test and post-test data from the experimental and control classes produced a significance value of 0.263, which is higher than the significance thres-hold of 0.05, according to the findings of the homogeneity test. This suggests that there is no significant difference between the two groups. Thus, it can be said that the data satisfy the presumptions needed to move on with the Independent Samples T-test in order to investigate the impact of employing virtual reality learning materials on fourth-grade students at SDIT Al-Ishlah Sudimampir in comparison to traditional media, such PowerPoint.

The significant value (Sig. 2-tailed) was 0.000, below the significance level of 0.05, according to the Independent Samples T-test findings. A statistically significant difference between the groups is shown by this. Thus, it can be said that using Virtual Reality (VR) learning materials significantly improves fourth-grade students' critical thinking abilities at SDIT Al-Ishlah Sudimampir when compared to traditional learning materials.

Table 5. Result independent samples test

Independent Samples Test										
		Levene's Test for		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Hasil_posttest_eksperimen_posttest_kontrol	Equal variances assumed	1.686	0.2	11.755	52	0	34.815	2.962	28.872	40.758
	Equal variances not assumed			11.755	47.633	0	-34.815	2.962	28.859	40.771

Table 6. Result descriptive statistics

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
ngain_skor_kontrol	25	0.36	0.63	0.5193	0.07074
ngain_skor_persen_kontrol	25	36.36	62.5	51.933	7.07357
ngain_skor_eksperimen	27	0.55	1	0.7555	0.14323
ngain_skor_persen_eksperimen	27	54.55	100	75.5499	14.32283
Valid N (listwise)	25				

The average increase in critical thinking skills in the control group was only 51.93%, which falls into the medium category and indicates low variation among students (as shown by the small standard deviation). Meanwhile, the average improvement in the experimental group was significantly higher (75.55%), classified as high, and showed greater variation among students compared to the control group. Thus, these results indicate that the use of Virtual Reality (VR) media in the experimental group was more effective in improving critical thinking skills compared to conventional learning in the control group. According to the experimental class's N-Gain data, the average score was 0.7555, placing it in the top range. This suggests that the experimental group's critical thinking abilities were significantly enhanced by the use of Virtual Reality (VR) instructional materials. The control group, on the other hand, had an average N-Gain score of 0.5193, which is in the moderate range. This indicates that the usage of traditional learning resources, like Power Point, also helped students strengthen their critical thinking abilities. Nonetheless, the experimental class's higher N-Gain score indicates that VR learning materials are more effective than traditional approaches in improving students' critical thinking skills.

The Virtual reality (VR) learning materials were successfully incorporated into the science curriculum for fourth-grade students at SDIT Al-Ishlah Sudimampir. This is corroborated by the researcher's observations made during the learning process, which show that the implementation component was rated as "excellent" and had a 100% success rate. Every step of the learning process was carried out as best as possible and in compliance with the lesson plan, from the presentation of challenging questions to the completion of reflection and assignment tasks. This achievement also shows how well the instructor supported the usage of VR materials in the classroom. The instructor successfully linked the course material to the students' real-world experiences in addition to assisting them in using the gadgets and exploring virtual information. This encouraged students to be more actively engaged in the learning process. Students were inspired to participate more fully in the learning process as a result. Students' logical and systematic thought processes were indirectly boosted by the usage of Virtual Reality (VR) learning materials, which allowed them to learn more efficiently in an immersive and contextual setting (16). This medium strengthens students' conceptual comprehension and increases their interest and drive to study through realistic visual representations (17).

Through realistic visual representations, virtual reality (VR) instructional materials provide pupils the chance to hone their critical thinking abilities. Their mental knowledge is deepened by this medium, which also encourages curiosity and a love of learning (18). This result is consistent with study by Oktarizka and Abidin, which shows that using Virtual Reality (VR) media to improve students' critical thinking abilities is very successful since it offers interesting and significant learning opportunities. Virtual reality (VR) produces extremely immersive

and dynamic learning environments that actively assist the development of critical thinking by fusing real-world information with virtual aspects created by digital devices (19).

As a result, in addition to being executed perfectly and rated as "very good," the use of Virtual Reality (VR) instructional materials also significantly improved students' critical thinking abilities. By encouraging students to think logically, methodically, and independently, virtual reality (VR) created an engaging and contextual learning experience that effectively facilitated the development of higher-order thinking abilities. Based on Piaget's theory of cognitive development, every child has the potential to develop their thinking abilities through active interaction with their environment. Innovations in instructional media can serve as important stimuli in the processes of assimilation and accommodation, enabling children to construct new cognitive structures and think in a more complex and logical manner.

After using VR as a learning tool, students in the experimental group showed a statistically significant improvement in their critical thinking abilities, according to the data analysis results. From 51.85 on the pre-test to 86.67 on the post-test, the average score rose. Interestingly, increases of more than 25% were observed in all four critical thinking indicators: analyzing, evaluating, concluding, and explaining. The realistic and engaging visual representations in the VR-based learning environment successfully encourage deep, contextual thinking. As a result of this change, learning is no longer a passive process but rather one in which students actively comprehend, analyze, and critically and logically evaluate knowledge (20).

As a result of this change, the majority of students' critical thinking abilities were no longer categorized as "Fair" or "Low," but rather as "Critical" or "Highly Critical," with the majority attaining the highest level. This change demonstrates how well virtual reality can be used as a teaching tool to provide engaging, cognitively demanding learning experiences that promote the development of higher-order thinking abilities (21). Additionally, virtual reality-based education has demonstrated efficacy in establishing a setting that actively fosters students' cognitive engagement. Students are engaged in and explore the material digitally rather than passively, which encourages them to examine data, assess circum-stances, and make decisions using logical and reflective thinking (22). This result is consistent with a research by Khotima et al. that showed how virtual reality may produce intricate and contextual learning simulations that allow students to assess, consider, and decide morally within pertinent religious situations (23). Therefore, it can be said that using virtual reality as a teaching tool can improve students' critical thinking abilities by providing them with immersive, significant, and intellectually stimulating experiences.

When compared to traditional Power Point-based training, the data analysis results show that using Virtual Reality (VR) as a learning tool significantly improves students' critical thinking abilities. This is corroborated by the Independent Samples T-

Test findings, which showed that H_0 was rejected and H_1 was accepted with a significance value of 0.000 (< 0.05). These results demonstrate that VR-based learning resources much surpass traditional approaches in enhancing students' capacity for critical thought. Through the use of virtual reality (VR), students may connect with the course material in a more tangible, visible, and interactive way, which promotes critical thinking, deeper thinking, and decision-making based on simulations that are provided digitally (23). The N-gain score analysis of the experimental group, which showed an average score of 0.7555, classified as high, provides additional proof of the effectiveness of VR as an educational medium. An average increase of 75.55% in percentage terms shows that most students saw significant progress once VR-based learning was implemented.

In addition to having a statistically significant impact, virtual reality gives pupils a rich and fulfilling educational experience that eventually helps them develop their critical thinking abilities more thoroughly (24). This result is in line with the Abidin study, which showed a substantial influence on students' critical thinking abilities, as shown by a p-value of less than 0.05. As a result, it can be said that using virtual reality (VR) as a teaching tool significantly enhances students' capacity for critical thought. This is reinforced by immersive, visual, and meaningful learning experiences that promote deeper and more thoughtful engagement with the learning material, as well as by the statistical test results and high N-gain scores (25).

CONCLUSION

The implementation of Virtual Reality (VR) as a learning medium in science instruction for fourth-grade students at SDIT Al-Ishlah Sudimampir has proven to be both highly successful and impactful. The entire learning process, from the delivery of thought-provoking questions to the stages of reflection and assignment, was executed optimally and categorized as “excellent” based on teacher observation. The VR-based learning approach successfully facilitated a shift from passive learning toward an active and engaging environment, where students were encouraged to think rationally, methodically, and independently.

The statistical data further reinforce this success. The average score of students in the experimental group increased significantly from 51.85 (pre-test) to 86.67 (post-test), with improvements exceeding 25% across all four critical thinking indicators: analyzing, evaluating, concluding, and explaining. Additionally, the majority of students achieved the highest competency level in critical thinking, which resulted in a significant change in the classification of students' critical thinking skills from mostly "Fair" and "Low" to fully "Critical" and "Highly Critical." A high N-gain score of 0.7555, or 75.55% gain, further confirmed these results and showed significant learning progress once VR-based instruction was implemented.

In addition to statistical gains, virtual reality (VR) offered students a meaningful and cognitively engaging learning experience that allowed them to engage with the material in a contextualized and visual way.

Students were prompted to reflect, analyze, and use reasoning since they were able to experience the material virtually rather than just absorbing it. This method strengthened their conceptual knowledge and helped them comprehend the subject matter more thoroughly. The result of the hypothesis testing were used to confirm the main findings aligned with the research objectives, namely to determine the effectiveness of using Virtual Reality (VR media in enhancing students' critical thinking skills.

Furthermore, the results of earlier research, including those by Oktarizka, Abidin, and Khotima et al., which highlight VR's ability to replicate intricate learning settings and facilitate morally sound, analytical decision-making, are consistent with the effectiveness of VR in fostering critical thinking. Thus, it can be said that virtual reality is a transformative tool for developing higher-order thinking skills in addition to being an effective teaching medium for science education. Its incorporation into the classroom has encouraging ramifications for upcoming teaching strategies meant to enhance cognitive development and student engagement. Thus, it can be said that virtual reality is a transformational tool for the development of higher-order thinking abilities in addition to being an excellent teaching medium for science learning.

Its use into the classroom has encouraging ramifications for upcoming instructional approaches meant to improve student engagement and cognitive development. This study still has limitations in terms of implementation time, number of subjects, and the scope of the material used. Therefore, future researchers are advised to conduct studies with a broarder scope, both in terms of educational levels, sample size, and variation of learning materials. Furhermore, further development can be carried out by exploring the application of Virtual Reality (VR) media in combination with other student-centered learning models to examine its effectiveness on various aspects of student abilities. These aspects are not limited to critical thinking skills but may also include collaborative skills, problem-solving abilities, and the reinforcement of conceptual understanding in a more comprehensive manner.

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