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Augmented Reality in Learning: Its Impact on the Understanding of Abstract Concepts

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ABSTRAK

This study aims to examine the effect of virtual reality simulation-based learning on students' empathy compared to video-based learning and non-technology instruction. An experimental randomized controlled trial with a pre-post test design involving three groups was employed. A total of 120 undergraduate students aged 18–25 years participated and were equally assigned to a VR simulation group, a video-based learning group, and a control group. The Interpersonal Reactivity Index and the Jefferson Scale of Empathy Student Version were used as research instruments. Data were analyzed using repeated measures ANOVA and Structural Equation Modeling–Partial Least Squares. The results indicate that the VR simulation group demonstrated a significantly higher increase in empathy compared to the other groups. Structural modeling further revealed that VR simulation had a positive and significant effect on empathy, with a stronger influence than video-based learning. These findings suggest that VR-based learning is effective in enhancing empathy through immersive learning experiences that integrate cognitive and emotional engagement.

INTRODUCTION

Difficulties experienced by students in understanding abstract concepts remain a fundamental problem in formal learning practices, particularly in disciplines that require high-level mental representation skills such as science, mathematics, and technology. Abstract concepts often lack direct references in students' concrete experiences, thereby demanding complex cognitive processes to construct meaningful conceptual understanding. When instructional processes fail to optimally facilitate the formation of such mental representations, students tend to encounter difficulties in comprehending conceptual structures, integrating knowledge, and transferring concepts to new contexts (Guntur & Setyaningrum, 2021; Su et al., 2022).

In conventional learning practices, instructional delivery is still predominantly based on written texts and static two-dimensional visuals. This approach is often insufficient to support the concretization of abstract concepts, particularly for learning materials that require complex spatial visualization and structural relationships. As a result, learning tends to emphasize procedural memorization rather than deep conceptual understanding. This condition contributes to low levels of higher-order cognitive achievement and limited problem-solving abilities among students (Chonchaiya & Srithammee, 2025; Mansour et al., 2024).

The rapid development of digital learning technologies over the past decade has opened new opportunities to address these limitations. Augmented Reality is one such technology that enables the integration of three-dimensional virtual objects into real-world environments in an interactive and real-time manner. The visual, immersive, and manipulable characteristics of Augmented Reality make it a promising learning medium for supporting the understanding of abstract concepts through more concrete and meaningful learning experiences. Through direct visualization and interaction with virtual objects, students are able to construct more accurate and integrated conceptual representations (Dewi, 2025; Rohendi et al., 2025).

At the international level, the use of Augmented Reality in education has expanded rapidly across various disciplines. Numerous studies report that this technology enhances the quality of learning experiences, cognitive engagement, and learning outcomes, particularly for abstract and complex subject matter. Meta-analyses and systematic reviews further indicate that Augmented Reality has significant potential to improve learning outcomes, especially in science, mathematics, and medical education contexts (Su et al., 2022; Zhang et al., 2022; Zhang et al., 2025).

Nevertheless, empirical findings regarding the impact of Augmented Reality on the understanding of abstract concepts remain inconsistent. While some studies report significant improvements in cognitive achievement, others suggest that the effectiveness of Augmented Reality depends on learning contexts, student characteristics, and the quality of instructional media design. This variation indicates that the effectiveness of Augmented Reality cannot be attributed solely to the presence of technology, but must be examined within a broader pedagogical and cognitive framework (Arnoldus et al., 2025; Son et al., 2025).

In the context of national education systems, the adoption of Augmented Reality remains relatively limited and is often positioned as a technical innovation rather than an evidence-based pedagogical instrument. The development of Augmented Reality learning media tends to focus on visual appeal and technological novelty, while systematic evaluations of its impact on students' conceptual understanding remain scarce. This condition highlights the need for experimental research capable of providing causal evidence regarding the effectiveness of Augmented Reality in improving abstract conceptual understanding (Ratnasari et al., 2025; Siki & Leba, 2025).

From an academic perspective, much of the existing research on Augmented Reality in learning emphasizes affective dimensions such as learning motivation, interest, and student engagement. While these aspects are important, the dominance of affective-focused studies has limited insights into the contribution of Augmented Reality to deeper cognitive constructs. In addition, many studies rely on simple statistical analyses that are insufficient for modeling latent relationships among cognitive dimensions in a comprehensive manner (Angraini et al., 2023; Husna et al., 2025).

Methodological limitations are also evident in the lack of studies that combine rigorous experimental designs with structural modeling approaches. Most existing research depends on pre-test and post-test score comparisons without accounting for the latent structure of the measured constructs. In fact, abstract conceptual understanding is a multidimensional construct formed through interactions among various cognitive indicators, thus requiring analytical approaches capable of capturing the complexity of these relationships (Su et al., 2022).

Based on this review, several significant research gaps can be identified. First, there is a lack of studies employing randomized controlled trial designs to causally examine the effectiveness of immersive technologies in learning abstract concepts. Second, the application of structural modeling approaches to analyze latent constructs in Augmented Reality-based learning contexts remains limited. Third, abstract conceptual understanding has not been sufficiently positioned as a primary cognitive construct in empirical models of technology-enhanced learning.

This study offers novelty in both methodological and conceptual aspects. Methodologically, it integrates a randomized controlled trial design with latent construct analysis to provide a more comprehensive understanding of the impact of learning interventions. Conceptually, this study positions conceptual understanding as the primary focus in evaluating the effectiveness of learning technologies, thereby strengthening the role of immersive technologies as evidence-based pedagogical instruments.

Based on the above considerations, the objective of this study is to analyze the effect of immersive simulation technology on improving students' conceptual understanding compared to conventional video-based learning and learning without technological intervention. This study is expected to contribute theoretically to the field of technology-enhanced learning and practically to educators in designing effective, evidence-based digital learning interventions.

METHODOLOGY

Research Design

This study employed an experimental design using a randomized controlled trial (RCT) with a pre-post test design involving three groups: a VR simulation group, a traditional video-based learning group, and a control group. This design was selected to control potential confounding variables and to enable causal analysis of the effects of different learning interventions on empathy improvement.

Population and Sample

The research population consisted of undergraduate students aged 18 to 25 years enrolled at a state university in Jakarta. Samples were selected using probability sampling based on the following inclusion criteria: active undergraduate students in semesters two to six, no history of mental disorders, no prior experience using VR technology, and willingness to participate in the study. The exclusion criteria included experiencing motion sickness, having severe visual impairment, and failing to complete all research sessions. Sample size estimation was conducted using G*Power version 3.1.9.7 with a medium effect size ($f = 0.25$), significance level of 0.05, and statistical power of 0.80 for repeated measures ANOVA with three groups and two measurement points, resulting in a minimum required sample of 108 participants. Considering a potential dropout rate of 10%, a total of 120 participants were recruited and evenly distributed across the three groups, with 40 participants in each group.

Research Instruments

Empathy was measured using the Interpersonal Reactivity Index (IRI) and the Jefferson Scale of Empathy (JSE) Student Version. The IRI consists of 28 items covering four subscales: Perspective-Taking representing cognitive empathy, Empathic Concern representing emotional empathy, Fantasy Scale, and Personal Distress. All items were measured using a Likert scale ranging from 0 to 4. In this study, the reliability coefficients were Cronbach's alpha of 0.83 for Perspective-Taking and 0.81 for Empathic Concern. The JSE Student Version comprises 20 items measured on a Likert scale ranging from 1 to 7 and assesses empathy in interpersonal relationship contexts, with a Cronbach's alpha of 0.85. In addition, a demographic questionnaire was used to collect data on participants' age, gender, study program, semester, and prior experience with VR technology

RESULTS AND DISCUSSION

Sample Characteristics

A total of 120 undergraduate students fully participated in this study, and all collected data were deemed suitable for analysis. The respondents consisted of 62 female participants and 58 male participants, aged between 18 and 25 years. All participants were active students in their second to sixth semesters and had no prior experience in using virtual reality technology. The balanced distribution of participants across the three groups (the VR simulation group, the video-based learning group, and the control group) indicates that the randomization process was conducted proportionally, thereby minimizing potential baseline bias among groups.

Pre-test and Post-test Results

An initial analysis was conducted to ensure equivalence in empathy levels prior to the intervention. The results of the ANOVA test on pre-test scores revealed no statistically significant differences among the groups, indicating that all groups were in comparable baseline conditions. Following the learning intervention, the results of the repeated measures ANOVA demonstrated a statistically significant difference in post-test empathy scores across groups. The VR simulation group exhibited the highest increase in empathy scores compared to the video-based learning group and the control group, confirming the effect of immersive technology-based interventions on enhancing students' empathy levels (Mansour et al., 2024; Zhang et al., 2025).

Measurement Model Evaluation

The measurement model evaluation was conducted to ensure the validity and reliability of the latent construct of empathy. Table 1 presents the results of the outer model evaluation, including factor loadings, Cronbach's alpha, composite reliability, and average variance extracted.

Table 1. Measurement Model Evaluation Results

Construct	Indicator	Loading	Composite Reliability	AVE
Cognitive Empathy	CE1	0.82	0.90	0.64
	CE2	0.79		
	CE3	0.84		
Emotional Empathy	EE1	0.81	0.89	0.62
	EE2	0.77		

	EE3	0.85		

All indicators exhibited factor loading values above 0.70, and the Average Variance Extracted (AVE) values exceeded the minimum threshold of 0.50, indicating that the construct demonstrated satisfactory convergent validity. Furthermore, composite reliability values greater than 0.70 confirmed adequate internal consistency reliability of the measurement model (Sarwono & Handayani, 2021).

Discriminant validity was assessed using the Fornell–Larcker criterion, as presented in Table 2.

Table 2. Discriminant Validity (Fornell–Larcker Criterion)

Construct	Cognitive Empathy	Emotional Empathy
Cognitive Empathy	0.80	
Emotional Empathy	0.61	0.79

The square root of the AVE for each construct was higher than the inter-construct correlations, indicating that discriminant validity was adequately established.

Structural Model Evaluation

The structural model evaluation was conducted to examine the effect of the type of learning intervention on empathy. The R-square value for the empathy construct was 0.41, indicating that the model explained 41 percent of the variance in students' empathy. Table 3 presents the path coefficients and significance testing results obtained through the bootstrapping procedure.

Table 3. Path Coefficients and Hypothesis Testing

Path	Coefficient	t-value	p-value
VR Simulation → Empathy	0.64	8.97	0.000
Video-Based Learning → Empathy	0.32	3.45	0.001

These results indicate that VR-based simulation learning has a positive and significant effect on students' empathy, with a larger effect coefficient compared to video-based learning. Therefore, the research hypothesis stating that VR-based learning is more effective in enhancing empathy than conventional methods is empirically supported.

Empirical and Theoretical Validation of the Effect of VR Simulation on Empathy Enhancement

The findings demonstrate that VR-based simulation learning has a positive and significant impact on students' empathy compared to video-based learning and learning without technological intervention. These results directly validate the research hypothesis and indicate that different types of learning interventions lead to meaningful differences in empathy levels. Empirically, the repeated measures ANOVA results show that the VR simulation group experienced the highest increase in empathy scores, while the SEM–PLS analysis reinforces this finding by revealing a large and significant path coefficient from VR simulation to the empathy construct.

The consistency between the experimental group comparison and structural modeling results indicates that the observed increase in empathy is not coincidental but rather the outcome of a structured and internalized learning mechanism. The randomized controlled trial design allows for stronger causal attribution, suggesting that the observed differences in empathy can be explained as a direct consequence of VR-based learning experiences. This finding is consistent with Dhar et al. (2021), who reported that immersive learning experiences enhance empathy through deeper emotional and cognitive engagement compared to conventional instructional media.

From a theoretical perspective, these findings can be explained through the concept of embodied learning, which emphasizes that understanding and empathy are formed through bodily engagement, perception, and direct experience. VR simulations enable learners to "experience" learning situations from a first-person perspective rather than merely observing them externally. This supports the process of perspective taking, which constitutes a core dimension of cognitive empathy. This interpretation aligns with Mansour et al. (2024), who argue that immersive technologies facilitate experiential learning that strengthens conceptual understanding and empathy formation.

Moreover, the larger effect coefficient of VR simulation compared to video-based learning suggests that the difference lies not in the instructional content itself but in how the content is experienced by learners. Video-based learning remains observational and relatively passive, whereas VR simulations position learners as active subjects within the learning environment. This finding supports Zhang et al. (2025), who emphasize that the degree of immersion and psychological presence plays a critical role in enhancing empathy and interpersonal understanding.

Accordingly, these findings strengthen empirical evidence that VR simulations enhance empathy not only statistically but also conceptually through learning mechanisms that align with cognitive and affective theories. The results confirm that the observed increase in empathy is not merely a novelty effect of technology but rather a consequence of deep interaction between learners and immersive learning environments.

Immersive Learning Mechanisms and Their Implications for Empathy Development

The significant influence of VR simulation on students' empathy can be explained through learning mechanisms that integrate cognitive and emotional dimensions simultaneously. In VR simulations, learners are exposed to situations that require understanding others' perspectives, thereby activating cognitive empathy through perspective-taking processes. This mechanism is consistent with the study's findings, which indicate a strong contribution of cognitive empathy dimensions to the overall empathy construct.

In addition to perspective taking, VR simulations facilitate emotional engagement through realistic situational representations. Immersive virtual environments enable learners to experience social and emotional contexts more vividly than two-dimensional media. This condition strengthens affective empathy, particularly empathic concern, as reflected in the increased post-intervention empathy scores. These findings are consistent with Lampropoulos et al. (2025), who highlight the strong potential of immersive learning in shaping emotional sensitivity and empathic responses.

From the perspective of multimedia learning theory, VR simulations also contribute to reducing extraneous cognitive load by presenting information in an integrated learning environment. Learners do not need to perform complex mental translations between text, images, and verbal explanations, as information is delivered contextually and holistically. This allows cognitive resources to be allocated more efficiently toward meaning-making and empathic reflection. This mechanism supports Zhang et al. (2022), who found that immersive technologies enhance learning effectiveness through improved information integration.

Nevertheless, the findings also indicate that the effectiveness of VR simulations depends heavily on the quality of instructional design. Individual differences in responses to immersive experiences suggest that not all learners benefit equally. However, this variation does not negate the overall pattern of results, as VR simulations consistently demonstrate a significant and robust effect on empathy at the aggregate level. This underscores that VR technology should be understood as a pedagogical tool whose effectiveness is determined by its alignment with learning objectives.

Overall, this discussion demonstrates that the observed increase in empathy is theoretically justifiable and logically derived from immersive learning mechanisms. VR simulations support empathy development through perspective-based experiences, emotional engagement, and cognitive integration, all of which align directly with the empirical findings and support the proposed research hypothesis.

CONCLUSION

This study concludes that VR-based simulation learning has a positive and significant effect on enhancing students' empathy compared to conventional video-based learning and learning without technological intervention. Based on the randomized controlled trial design and structural modeling using SEM–PLS, VR simulations were shown to increase empathy both causally and consistently, as evidenced by pre-test and post-test score differences and the strength of latent construct relationships within the empathy model. These findings indicate that immersive learning experiences play a substantive role in shaping empathy through mechanisms that integrate cognitive and emotional engagement simultaneously.

Theoretically, this study contributes to technology-enhanced learning research by demonstrating that empathy can be conceptualized as a modifiable latent construct through appropriate pedagogical interventions. VR simulations support perspective taking and empathic concern by providing embodied and contextualized learning experiences. Practically, the findings suggest that the integration of VR technology in education should be pedagogically driven and oriented toward affective–cognitive learning objectives rather than focusing solely on technological innovation.

As a recommendation, future research may explore variations in VR simulation scenario design and intervention duration to examine the sustainability of learning effects. Additionally, testing the empirical model across different institutional contexts and academic disciplines would help expand the generalizability of the findings.

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