



ENHANCING MATHEMATICS CONCEPTUAL UNDERSTANDING THROUGH VIRTUAL REALITY-BASED STEAM LEARNING: EVIDENCE FROM UNIVERSITY STUDENTS

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Abstract :

Virtual Reality (VR) integrated into Science, Technology, Engineering, Arts, and Mathematics (STEAM) learning offers opportunities to create more exploratory mathematics learning experiences. Virtual environments can visualize objects, geometric forms, spatial relationships, and phenomena that are difficult to represent through conventional instructional media. This study aimed to examine students' responses to VR-based STEAM learning and its relevance to mathematics conceptual understanding. A quantitative approach was employed, using a structured questionnaire administered once to students in the Mathematics Education Study Program, Faculty of Teacher Training and Education, Universitas Kristen Indonesia. Descriptive statistics were used to analyze response frequencies, percentages, mean, median, and standard deviation. The findings showed generally positive student responses to the learning experience. Of the 840 respondents, 57% agreed and 30% strongly agreed with the questionnaire statements, while 10% disagreed and 2% strongly disagreed. The mean score was 3.08, with a median of 3 and a standard deviation of 0.72. These findings indicate favorable student perceptions of VR-based learning and suggest its potential to support engagement with mathematical concepts through immersive visualization and interdisciplinary exploration. However, the results reflect students' reported perceptions rather than direct evidence of improved conceptual understanding. Further research using direct assessments of mathematics conceptual understanding is needed to establish the educational effectiveness of VR-based STEAM learning.

Keywords: Virtual Reality; STEAM Learning; Mathematics Education; Higher Education

INTRODUCTION

Advances in knowledge and technology have driven transformations across various aspects of life, including higher education. The integration of digital technology into learning is no longer limited to providing online learning resources but has evolved toward more interactive, adaptive, collaborative, and experience-oriented learning environments (Hui, 2026). This transformation creates opportunities for higher education institutions to develop instructional strategies that not only facilitate content mastery but also encourage students to construct knowledge through contextualized and meaningful learning experiences (Godwin-Jones, 2023). In this context, technology should not be regarded merely as an instructional aid but as an integral component of pedagogical design that supports active engagement and the development of higher-order thinking skills.

Virtual Reality (VR) technology enables the creation of three-dimensional



virtual environments that provide immersive learning experiences through visualization, interaction, and direct exploration of objects (Mulders, Buchner & Kerres, 2020). These characteristics distinguish VR from conventional instructional media, which generally present information through two-dimensional formats or static representations. Within virtual environments, students can observe objects from multiple perspectives, explore relationships among components, and engage with richer visual and spatial experiences (Rubio-Tamayo, Gertrudix Barrio & García García, 2017). Accordingly, VR has the potential to support learning processes that require concrete representations of concepts that are otherwise difficult to observe directly.

This potential is particularly relevant to mathematics education because mathematics involves not only procedures and calculations but also an understanding of concepts, relationships, patterns, structures, and abstract representations (Goldin & Shteingold, 2001). University students often encounter difficulties when connecting symbolic representations with visual or spatial representations of mathematical concepts. Instruction that focuses excessively on procedures may enable students to obtain answers algorithmically without developing an adequate conceptual understanding of the reasoning and relationships underlying those procedures. Therefore, mathematics education in higher education requires approaches that connect mathematical abstraction with visual, exploratory, and contextualized learning experiences (Richland, Stigler & Holyoak, 2012; Goldin, 2020).

In contemporary education, this need aligns with the Science, Technology, Engineering, Arts, and Mathematics (STEAM) approach, which integrates multiple disciplines into a multidisciplinary learning process. STEAM provides opportunities for students to connect mathematical concepts with technology, problem-solving, design, creativity, and real-world contexts. Integrating STEAM into mathematics education may shift the emphasis from procedural mastery toward understanding, applying, exploring, and constructing concepts through more authentic learning situations (Bertrand & Namukasa, 2023). Integrating VR into STEAM-based learning offers opportunities to create more exploratory mathematics learning experiences. Virtual environments can be used to visualize objects, geometric forms, spatial relationships, and phenomena that are difficult to represent through conventional instructional media. Within a STEAM framework, these experiences can be extended through activities that encourage students to investigate problems, explore representations, develop solutions, and connect mathematical concepts with other fields of knowledge (Pramasdyahsari et al., 2025). Thus, VR is not treated as a standalone technology but as part of an instructional strategy designed to strengthen knowledge construction and conceptual understanding.

Although the use of VR in education continues to expand, many studies have primarily examined technology acceptance, student engagement, learning experiences, or perceptions of VR use (Baxter & Hainey, 2020). Research specifically integrating VR with the STEAM approach and focusing on

university students' mathematical conceptual understanding warrants further investigation, particularly within higher education. Moreover, the effectiveness of educational technology depends not only on the sophistication of the devices but also on how the technology is integrated into learning objectives, student activities, and the characteristics of the subject matter. This situation highlights the need for research that positions VR as part of pedagogical design rather than merely as a technological innovation (Aluko et al., 2026). Mathematics Education students face the complex academic challenge of developing a deep understanding of mathematical concepts while preparing to translate that knowledge into learning experiences that school students can understand. Conceptual understanding, the ability to connect different forms of representation, and the application of concepts in relevant contexts are essential components of prospective mathematics teachers' professional competence. Consequently, learning experiences that enable students to explore mathematical concepts visually, interactively, and contextually are increasingly important. In this regard, VR should be examined not only in terms of the feasibility or validity of the instructional medium but also in relation to how its implementation may support learning processes and strengthen students' conceptual understanding.

The urgency of this research is further reinforced by the growing need for higher education institutions to integrate digital technologies into teaching in pedagogically meaningful ways. The use of technology does not automatically produce better learning experiences; its benefits depend largely on the alignment between technological characteristics, learning objectives, instructional content, and student activities. Therefore, research on VR implementation in mathematics education should provide empirical evidence regarding how the technology is used in learning, how students respond to and interact with virtual environments, and the extent to which these experiences contribute to mathematical conceptual understanding. Such evidence is important to ensure that VR implementation extends beyond technological novelty and delivers meaningful pedagogical value in higher education.

This study was conducted in the Mathematics Education Study Program, Faculty of Teacher Training and Education, Universitas Kristen Indonesia (UKI), which is committed to developing high-quality, independent, and innovative education in the implementation of the university's Tri Dharma mission. The introduction of VR into the program's learning activities represents an effort to respond to developments in educational technology while creating more interactive and contextualized learning experiences for students. This context provides a relevant setting for empirically examining VR implementation in higher education mathematics, particularly in relation to students' conceptual understanding.

This study aimed to obtain empirical evidence regarding students' responses to VR-based STEAM learning and its relevance to mathematical conceptual understanding. Rather than treating VR solely as a technological innovation, the study examined it as part of a learning experience intended to

help students engage with mathematical concepts more meaningfully. The findings are expected to contribute to the development of technology-enhanced mathematics education in higher education and provide empirical considerations for designing learning experiences for prospective mathematics teachers in the era of digital transformation.

Theoretical Review

Virtual Reality Media

Virtual Reality (VR) is a technology that enables users to interact with three-dimensional virtual environments designed to simulate experiences resembling real-world situations. In education, VR can serve as an instructional medium that presents objects, phenomena, and learning situations through visual and interactive experiences. Unlike conventional instructional media, which tend to present information in static, two-dimensional formats, VR allows students to explore virtual environments, observe objects from multiple perspectives, and interact directly with the elements within those environments (Maroukakis et al., 2023). These characteristics make VR particularly relevant for learning content that requires visualization, spatial exploration, and an understanding of relationships among components.

Learning experiences facilitated by VR can be understood through several key characteristics: immersion, presence, empathy, and embodiment (Fussell & Truong, 2022). Immersion refers to the extent to which users become engaged in a virtual environment, allowing their attention to focus on the experience being presented. Presence concerns users' perceptions of feeling as though they are physically situated within the virtual environment. Empathy refers to the capacity to understand experiences, perspectives, or situations represented through simulations. Meanwhile, embodiment describes the experience of a perceived connection between users, their avatars, their actions, and the virtual environment. Together, these characteristics demonstrate that VR is more than a device for displaying three-dimensional objects; it constitutes a learning environment capable of providing interactive and multisensory experiences.

In mathematics education, these characteristics are particularly relevant because many mathematical concepts are abstract and require students to connect different forms of representation (Van den Heuvel-Panhuizen & Drijvers, 2020). Three-dimensional visualization in VR can help students examine shapes, structures, positions, spatial relationships, and changes in objects more concretely. Rather than relying solely on verbal explanations or mathematical symbols, students can explore objects and mathematical relationships through visual and interactive experiences (Mainali, 2021). This process may help connect concrete and visual representations with symbolic representations, thereby supporting the development of deeper conceptual understanding.

The use of VR also creates opportunities for student engagement across multiple competency domains. In the cognitive domain, VR can support observation, exploration, identification of relationships, and the construction of

understanding about the concepts being studied (Zhou, Xu & Wang, 2018). In the affective domain, immersive and interactive experiences may increase students' attention, interest, and engagement during learning activities. In the psychomotor domain, interactions with virtual environments may involve movement, navigation, object manipulation, and exploration, allowing students to learn through direct experience. The integration of these domains creates opportunities for mathematics education to move beyond information transmission toward more active and meaningful learning experiences. Nevertheless, the use of VR in education does not automatically guarantee the development of conceptual understanding. Its pedagogical value depends substantially on how the technology is integrated with learning objectives, subject matter characteristics, student activities, and instructional strategies. Therefore, VR should be positioned as a medium that supports knowledge construction rather than as an educational objective in itself. In higher education, VR becomes more meaningful when students do not merely observe virtual environments but also explore them, interpret information, connect visual experiences with mathematical concepts, and reflect on their learning outcomes.

STEAM-Based Learning

STEM (Science, Technology, Engineering, and Mathematics) is an integrated learning approach that connects science, technology, engineering, and mathematics through real-world problems. This approach enables students to explore relationships among disciplines through investigation, design, experimentation, and problem-solving activities. Such integration supports not only conceptual mastery but also the development of critical thinking, creativity, collaboration, and communication skills required in the twenty-first century. The development of STEM into STEAM involves incorporating the Arts (A) as an additional dimension that complements the learning process (Land, 2013). The inclusion of the arts is not merely a decorative activity; rather, it provides opportunities for students to express ideas, develop imagination, design creative solutions, and communicate their thinking through diverse forms of representation (Clapp & Jimenez, 2016). According to Talib et al. (2019), STEAM is a student-centered learning approach that enables learners to participate actively in exploration and knowledge construction.

Integrating the arts into STEM may also help strengthen student engagement and motivation. By combining scientific reasoning, technological applications, engineering processes, mathematical modeling, and creative expression, STEAM learning provides opportunities for students to develop a more meaningful understanding of connections among disciplines (Nuragnia & Usman, 2021). Furthermore, this approach can support independent learning, social responsibility, and creative problem-solving. Accordingly, STEAM can be understood as an interdisciplinary learning approach that integrates five fields to foster conceptual understanding, creativity, and the ability to apply knowledge in real-world contexts.

Research Method

This study employed a quantitative approach to examine students' engagement in Virtual Reality (VR)-based STEAM learning and its relevance to mathematics conceptual understanding. The instrument's internal consistency was examined using a single-administration approach, in which data were collected once from a single group of respondents using a structured questionnaire. Following data collection, descriptive statistical analyses were conducted to summarize the characteristics of the responses. These analyses included the mean, median, mode, standard deviation, minimum and maximum scores, and frequency distributions for each questionnaire item. The descriptive results provided an overview of students' responses to VR-based learning and served as an initial basis for examining their learning experiences in the context of STEAM-integrated mathematics education.

RESULTS AND DISCUSSION

Frequency Distribution of Students' Responses

Response Category	Frequency	Percentage
Strongly Agree	251	30%
Agree	478	57%
Disagree	89	10%
Strongly Disagree	22	2%
Total (N)	840	100%

Statistics of Students' Responses to VR-Based STEAM Learning

Mean	Median	Standart Deviasi (SD)
3.081081081	3	0.7235648

Statistical results indicate that students generally expressed positive perceptions of VR-based learning in the context of mathematics education. The mean score was 3.08, with a median of 3 and a standard deviation of 0.72. The mean score suggests that students' responses tended toward agreement, while the median indicates that the central response was consistent with the agreement level on the four-point Likert scale. The relatively low standard deviation indicates that students' responses were moderately concentrated around the mean, although individual differences in their perceptions remained. These findings suggest that students generally responded favorably to the implementation of virtual reality as a learning medium. In the context of STEAM-based mathematics learning, VR may provide opportunities for students to explore visual representations of mathematical concepts and engage with learning environments that connect abstract ideas with more concrete

experiences. Such features may support students' engagement with mathematical content and provide opportunities for deeper conceptual exploration.

However, the descriptive statistics should be interpreted as evidence of students' reported perceptions rather than direct evidence that VR-based STEAM learning improved their mathematical conceptual understanding. Establishing an improvement in conceptual understanding would require additional evidence, such as conceptual understanding assessments or comparisons of students' performance before and after the learning intervention. Therefore, these results provide an initial indication of students' responses to VR-based learning and a basis for further investigating its potential contribution to mathematics conceptual understanding.

Students' Responses to Virtual Reality-Based STEAM Learning

The frequency distribution and descriptive statistical results indicate that students generally reported positive responses to virtual reality (VR)-based learning in the context of mathematics education. Of the 840 respondents, 475 students (57%) agreed and 251 students (30%) strongly agreed with the statements presented in the questionnaire. Combined, these responses accounted for approximately 87% of the participants, suggesting an overall favorable perception of the learning experience. In contrast, 83 students (10%) disagreed and 18 students (2%) strongly disagreed, indicating that a smaller proportion of students experienced less favorable perceptions of the implementation. The descriptive statistics reinforce this pattern. The mean score was 3.08, the median was 3, and the standard deviation was 0.72. The mean score indicates that responses tended toward agreement, while the median reflects a central response at the agreement level on the four-point Likert scale, assuming the scale was coded from 1 (strongly disagree) to 4 (strongly agree). The standard deviation suggests a moderate concentration of responses around the mean, although differences in students' experiences and perceptions remained.

In relation to the study's focus on enhancing mathematics conceptual understanding through VR-based STEAM learning, these findings provide an encouraging indication of students' acceptance of the learning approach. VR may offer opportunities to explore mathematical concepts through immersive visual representations and interactive environments, while the STEAM framework can connect mathematical reasoning with scientific inquiry, technological applications, engineering design, and creative expression. Together, these features may create learning opportunities that help students engage with abstract mathematical ideas in more contextualized and meaningful ways.

Nevertheless, favorable responses should not be interpreted as direct evidence that students' conceptual understanding of mathematics improved. The frequency distribution and descriptive statistics primarily reflect students' reported perceptions of the learning experience. Demonstrating improvement in conceptual understanding would require direct measures of mathematical

understanding, such as conceptual assessments, pretest–posttest comparisons, or other appropriate learning-outcome measures. Accordingly, the present findings suggest that students generally viewed the VR-based learning experience positively, providing a basis for further investigation of its contribution to conceptual understanding in STEAM-oriented mathematics education.

CONCLUSION

Students demonstrated generally positive responses to VR-based STEAM learning, with approximately 87% expressing agreement or strong agreement and a mean score of 3.08 (SD = 0.72). These findings indicate favorable student perceptions of the learning experience and suggest that VR-based STEAM learning may offer promising opportunities to support engagement with mathematical concepts. However, further assessment is needed to determine its actual contribution to students' conceptual understanding of mathematics.

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