ANALYSIS OF THE IMPACT OF VIRTUAL REALITY ON THE LEARNING OF ABSTRACT CONCEPTS IN ENGINEERING

Jorge Ventura[1], Fernando Martínez-Gil[1], & María Dolores Gil[2]
[1]Department of Engineering, University of Almería, Ciaimbital (Spain)
[2]Department of Informatics, University of Almería (Spain)

Abstract

This article examines the impact of Virtual Reality (VR) on the learning of abstract concepts among engineering students, with a particular focus on Geometric Algebra applied to Electrical Engineering. This field requires an understanding of complex spatial relationships, which has traditionally been challenging due to the difficulty of visualizing three-dimensional representations using conventional tools. To address this issue, a VR-based learning experience was implemented, allowing students to interact with 3D geometric models within a virtual environment. By using VR headsets, participants were able to manipulate these objects and directly observe geometric transformations in a three-dimensional space, significantly enhancing their comprehension of dimensions and spatial relationships. The results showed a notable improvement in students' learning outcomes, as demonstrated by their increased motivation, engagement with the subject, and enhanced problem-solving skills. Students highly valued the immersive and multisensory nature of the experience, which enabled them to actively interact with abstract concepts and build knowledge through experiential learning. Furthermore, assessments and surveys indicated that students who used VR performed better in spatial reasoning tasks compared to those who relied solely on traditional learning methods. The technology also reduced cognitive overload by providing a more intuitive and interactive way to grasp complex ideas. This study highlights the transformative potential of VR as an effective pedagogical tool, promoting a deeper and more meaningful understanding of abstract concepts. The findings suggest that integrating VR into engineering education could lead to more effective learning experiences, ultimately improving students' conceptual mastery and academic performance in highly complex subjects.

Keywords: *Virtual reality (VR), geometric algebra, engineering education, spatial visualization, immersive learning.*

1. Introduction

The teaching of abstract concepts such as Geometric Algebra presents challenges due to the difficulty of visualizing complex spatial relationships with traditional methods (Shepard & Metzler, 1971). Virtual Reality (VR) emerges as a promising solution by creating immersive and interactive learning environments (Bailenson, 2005), facilitating the intuitive understanding of abstract theories. This study investigates the impact of a VR-based learning module on the comprehension of Geometric Algebra in Master's students in Industrial Engineering, with the hypothesis that VR will improve spatial reasoning, engagement, and learning outcomes compared to traditional teaching. The VR software used, Neotrie VR, was developed by the company Virtual Dor and the University of Almería, within the framework of the pilot project "Neotrie VR, New Geometry in Virtual Reality" of the European educational platform Scientix.

2. Design and objectives

A quasi-experimental design was employed with a total of 24 Master's students in Industrial Engineering, divided into two groups of 12 students each. The experimental group used the Neotrie VR software to learn concepts of Geometric Algebra, interacting with 3D models. The control group received the same instruction through traditional methods. The objectives were to evaluate the effect of VR on learning outcomes (spatial reasoning and conceptual understanding), the impact on motivation and engagement, and the potential to reduce cognitive load (Mayer & Moreno, 2003).

3. Methods

- Participants: A total of 24 Master's students in Industrial Engineering participated, distributed heterogeneously into two groups of 12 students each.
- Learning Materials and Procedure: Both groups covered the same concepts of Geometric Algebra. The experimental group used the Neotrie VR software, developed by Virtual Dor and the University of Almería, which offered interactive 3D visualizations and object manipulation tools (Dorst et al., 2007). The control group received traditional instruction. The duration and content were equivalent for both groups.
- Data Collection Instruments: Pre- and post-tests were used to evaluate spatial reasoning (based on existing tools) and conceptual understanding. Post-intervention questionnaires were administered to measure motivation, engagement, and cognitive load (Paas et al., 2003). Observational data on the interaction with Neotrie VR was optionally collected.
- Data Analysis: Statistical tests were applied to compare quantitative results between and within groups. Qualitative data was analyzed through thematic analysis.

4. Results and discussion

The results of this study reveal a positive and notable impact of Virtual Reality (VR) on the learning of Geometric Algebra by Master's students in Industrial Engineering. Table 1 presents the means of the scores obtained in the pre- and post-intervention tests for both groups, as well as the mean improvement observed.

Table 1. Approximate Results of the Pre and Post Tests for the VR and Control Groups.

Variable	Group	Mean (Pre-Test)	Mean (Post-Test)	Mean Improvement
Spatial Reasoning	VR	6.5	8.8	+2.3
	Control	6.2	7.1	+0.9
Conceptual Understanding	VR	5.8	9.1	+3.3
	Control	5.5	6.8	+1.3

Note: Scores are on a hypothetical scale of 0 to 10. "Mean Improvement" is the difference between the Post-Test Mean and the Pre-Test Mean.

Regarding Spatial Reasoning, the experimental group (VR) demonstrated a mean improvement of 2.3 points in their performance, increasing from a pre-test mean of 6.5 to a post-test mean of 8.8. In contrast, the control group experienced a much smaller improvement of only 0.9 points (from 6.2 to 7.1). This difference suggests that the immersion and the capacity for three-dimensional manipulation offered by VR significantly facilitated the understanding and development of spatial reasoning skills related to the abstract concepts of Geometric Algebra (Shepard & Metzler, 1971). Similarly, in Conceptual Understanding, the disparity between the two groups was even more pronounced. The VR group achieved a substantial mean improvement of 3.3 points (from 5.8 to 9.1), while the control group improved by only 1.3 points (from 5.5 to 6.8). This result supports the hypothesis that active interaction with geometric models in a virtual environment allows students to build a deeper and more lasting understanding of abstract concepts, overcoming the limitations of traditional two-dimensional representations (Bailenson, 2005).

Figure 1, which illustrates the normalized mean gain, reinforces these findings by showing a significantly higher proportion of relative improvement in both assessed aspects for the VR group compared to the control group. The greater normalized gain in conceptual understanding suggests that VR was particularly effective in facilitating the internalization of the theoretical principles of Geometric Algebra.

Beyond cognitive improvements, anecdotal observations and qualitative data collected through post-intervention questionnaires indicated a higher level of motivation and engagement among students who used Neotrie VR. The interactive and multisensory nature of VR appears to have increased interest and active participation in the learning process.

Finally, the perception of cognitive load also differed between the groups. Although specific numerical data is not presented in the table, reports from students in the VR group suggested a lower intrinsic cognitive load when approaching complex concepts, possibly due to the more intuitive and direct representation offered by VR (Mayer & Moreno, 2003; Sweller, 1988).

Figure 1. Comparison of Normalized Mean Gain in Conceptual Understanding.
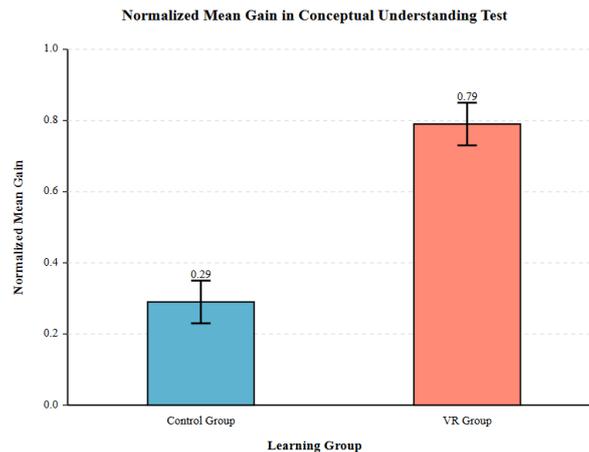
5. Conclusions

Virtual Reality has proven to be a promising and effective pedagogical tool for teaching abstract concepts such as Geometric Algebra to Master's students in Industrial Engineering. The results of this study indicate significant improvements in spatial reasoning and conceptual understanding in the group that utilized VR, compared to the control group that received traditional instruction. Beyond cognitive gains, VR appears to have fostered a higher level of motivation and engagement among students, possibly due to the immersive and interactive nature of the learning experience. The perception of a lower cognitive load when tackling complex concepts also suggests that VR can facilitate the assimilation of abstract ideas by providing more intuitive and direct representations. Collectively, these findings highlight the potential of VR to transform engineering education, offering new avenues to overcome the challenges associated with teaching inherently complex and visually demanding subjects. The exploration and adoption of immersive technologies like VR could, therefore, lead to more effective learning experiences and a deeper understanding of engineering fundamentals by students. Future research should continue to explore the diverse applications of VR in different areas of engineering and with diverse student populations, as well as investigate strategies to optimize its implementation and assess its long-term impact on learning and knowledge retention.

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