Validating an Immersive Virtual Environment for Learning 3D Transformations: From Design to Student Impact to Expert Evaluation

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Abstract

3D transformations are essential in computer graphics but remain difficult for students to master due to their abstract and spatially complex nature. This work presents a three-phase research study on the design, implementation, and validation of an immersive virtual environment that supports the learning of 3D transformations through direct interaction and real-time visual feedback with 3D objects. The study began with the design and pilot study of the tool, followed by a main study that assessed its impact on spatial skills and conceptual understanding among computer science students. To further validate its educational value, a survey was conducted with university educators experienced in teaching computer graphics and related disciplines. Findings across all studies indicate that the immersive environment is effective and engaging for supporting students' understanding of 3D transformations. This work contributes to the growing field of XR in computing education and offers evidence-based insights for future integration into teaching and learning practices.

Introduction

In computer graphics education, 3D transformations form a critical foundation for understanding how objects are visualized and manipulated in three-dimensional space. Despite their importance, these topics are often challenging for students to learn due to their abstract representations and the need for strong spatial reasoning skills (Suselo et al., 2022b). Traditional teaching approaches, which typically rely on static 2D visuals and textbook explanations, can make it difficult for learners to mentally visualize the effects of transformations in a 3D environment. Recent advancements in technologies, particularly virtual reality (VR), offer new possibilities for addressing these learning challenges. Immersive environments allow learners to interact directly with 3D objects (Korkut and Surer, 2023), observe the immediate effects of transformations from multiple perspectives, helping bridge the gap between abstract theory and intuitive spatial understanding. In this context, we developed an immersive virtual environment to support the teaching and learning of 3D transformations. This work presents the development of the immersive environment, examines its impact on student learning, and explores its validation through expert feedback, positioning the tool as a pedagogically sound and practically relevant solution for XR-supported computer graphics education.

Immersive Environment Design

The immersive learning environment was developed using Unity, C#, and OpenXR to ensure compatibility with a range of VR headsets. It was specifically designed to address the challenges students face in understanding visual representations and OpenGL commands while learning 3D transformations, by offering an interactive environment where users can manipulate 3D objects and receive immediate feedback. A key feature of the environment is its ability to trace the object's state before applying a transformation, allowing users to observe updated positions based on their input (as shown in Figure 53). Users can apply translation, rotation, and scaling individually or in sequence to explore their effects on object position and orientation. The system also integrates real-time OpenGL transformation commands, which dynamically update as users apply changes to objects in the scene (see Figure 2). This dual feedback (visual and textual) was intended to help students form clearer connections between abstract operations and their visual effects in a three-dimensional space. Users interact with the system through VR controllers, enabling them to apply transformations and observe the results from multiple angles. The environment also allows users to walk or fly through the 3D space, providing flexible movement for exploring objects from different perspectives. The interface was designed to reduce unnecessary complexity and cognitive load. The design is guided by the Cognitive Theory of Multimedia Learning (CTML), which emphasizes that learning is more effective when visual representations are paired with relevant textual information (Mayer, 2005). By aligning spatial interactions with immediate visual and code-based feedback, the environment helps students build mental models of 3D transformation processes in a meaningful and engaging way (Alobaid and Manzke, 2024).

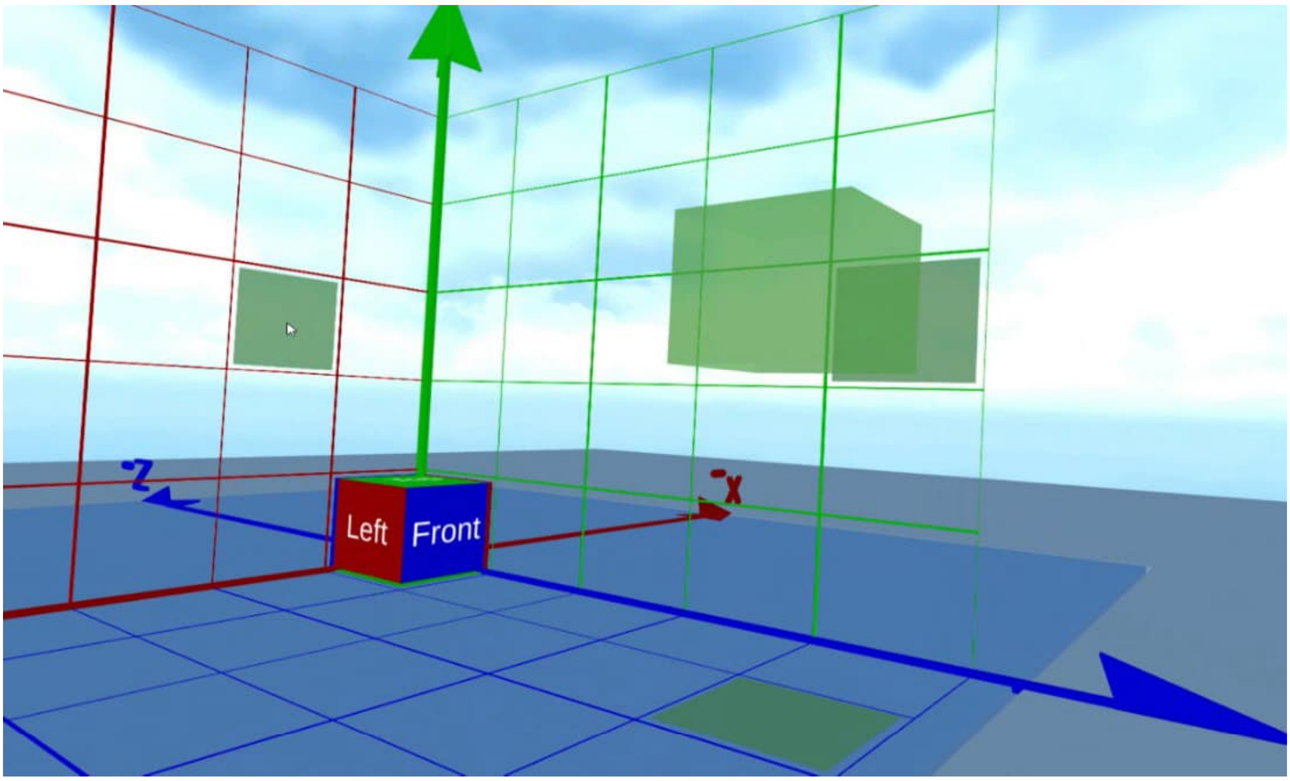

Figure 53. The trace feature to visualize the user's input.

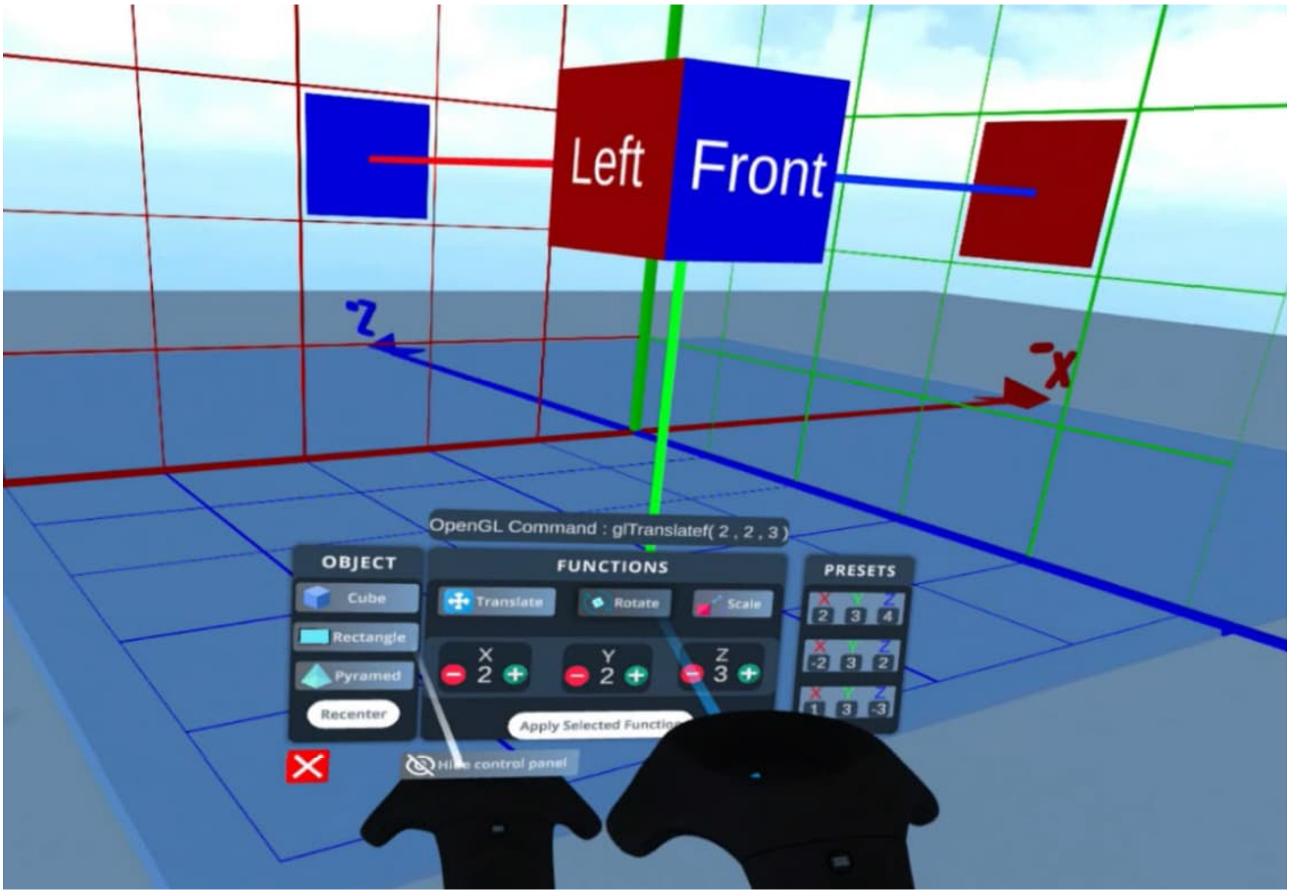

Figure 54. *Translation function with real-time OpenGL command in the VR environment.*

Pilot Study

The first phase of evaluation involved a pilot study aimed at exploring the usability and initial educational potential of the VR environment. Participants included seven users with extensive experience in VR and computer graphics. After a brief orientation session, they interacted with the environment and completed tasks involving 3D transformations without any time constraints. Feedback was gathered through post-session questionnaires. Findings indicated that participants found the environment intuitive and engaging. Most reported that the immersive setting helped them visualize how transformations affect objects in 3D space. At this stage, usability issues and areas for improvement were identified to enhance the environment for the main study.

Main Study

Building on the pilot, a larger lab controlled study was conducted to measure the effectiveness of the VR tool. The study involved 49 undergraduate and postgraduate computer science students who completed pre- and post-tests measuring their spatial reasoning and conceptual understanding of 3D transformations. They also completed surveys assessing engagement and perceived learning educational effectiveness. Results showed statistically significant improvements in spatial skills and contributed to deeper conceptual understanding after using the tool. Students expressed high levels of satisfaction with the VR experience and highlighted the value of being able to see and interact with transformations directly from different perspectives (Alobaid et al., 2025).

Expert Evaluation

To further evaluate the tool's pedagogical relevance from an expert perspective, a survey was conducted with 16 university educators from the Department of Computer Science. Participants included Professors, Associate Professors, Assistant Professors, and Lecturers, all of whom had varying years of teaching experience and expertise in computer graphics, programming, or VR. Experts first interacted with the immersive environment, then completed a questionnaire assessing its educational value, usability, and potential to enhance spatial ability in learning 3D transformations. Overall feedback was highly positive and strongly agreed that the VR tool supports learning by enabling students to directly engage with 3D transformations and improve spatial visualization. Several experts emphasized its potential impact and recommending its adoption as part of computer graphics courses at the college and suggestions to improve usability for novice students and sensitivity settings of the VR controller.

Conclusion and Future Work

This work presents the development and validation of an immersive VR environment designed to enhance the learning of 3D transformations in computer graphics. Across three studies a pilot, a main student evaluation, and an expert survey—the tool has demonstrated strong potential to improve student learning, engagement, and spatial reasoning. Future work will build on expert feedback by enhancing usability and further integrating the tool into computer graphics modules. An open-source version of the tool is also planned to support broader use and collaborative refinement in the computing education community. Additionally, further studies should be conducted to compare this approach with traditional teaching tools and to evaluate the long-term retention of learning outcomes, which would provide deeper insight into the educational effectiveness of the immersive environment.

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