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Work-in-Progress—Design of Immersive Virtual Reality Environment for Learning 3D Transformations

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Abstract. There are various opportunities to employ virtual reality in education. However, a lot of resources are required to create virtual reality learning opportunities. Designing educational activities and preparing them for study requires systematic efforts in order to show the value of learning in the future. This work-in-progress paper presents the design, development, and first evaluation of an immersive virtual reality learning environment for 3D transformations in computer graphics. The cognitive theory of multimedia learning (CTML) is the pedagogical framework for designing the immersive virtual environment. The foundation for investigative findings about the learning processes is put in place by using educational technologies at an early stage of development to improve the user learning experience.

Keywords: Virtual Reality, Immersive VR, CTML, Computer Graphics, 3D Transformations.

1 Introduction

Virtual reality (VR) is a term that refers to a fully rendered virtual world generated through computer technology. The creation and visualization of this alternate reality necessitate the use of hardware and software capable of generating a compelling immersive experience, such as VR headsets or specialized glasses equipped with 3D software [1]. VR technology provides a learning environment that is more focused and free from outside distractions by creating a highly immersive experience. Since the user is totally engrossed in the virtual setting and completely blocked out of the real world. The wide range of study disciplines that have used immersive technologies in teaching suggests that there is a considerable level of interest in these technologies for educational reasons [19]. Regarding the educational advantages offered by instructional VR, numerous research presents impressive assertions [20]. VR technologies, for instance, are utilized to more effectively and affordably convey educational content about human anatomy and surgical processes [21]. VR can provide users with unique perspectives that are hard to replicate in reality when used in cognitive learning tasks that need a high level of spatial knowledge and imagery. According to prior studies, activities of cognitive learning that need a high level of visualization and sensory comprehension are best supported by virtual technologies. 3D transformations are covered as a fundamental principle in many introductory computer graphics courses [2]. A significant challenge in learning computer graphics is the complexity associated with understanding 3D transformations [7]; students encounter challenges comprehending fundamental transformation questions that feature visual depictions and OpenGL code snippets [3]. The likely explanation is that a solid knowledge of spatial abilities is essential for comprehending 3D scenes and transformations [4]. To comprehend 3D transformations, you need to mentally manipulate items in any position and be knowledgeable about representational techniques, which closely relate to the idea of spatial abilities. Furthermore, it is also necessary to develop one's spatial visualizations to enhance learning. Understanding 3D transformations in immersive VR is based on the concept that immersive settings offer a more intuitive and natural approach for people to interact with and comprehend 3D spatial relationships. The integration of immersive VR technologies has the potential to enhance educational settings; however, their implementation frequently prioritizes technology over instructional principles [5]. Immersion VR technology-supported environments for learning should be designed with both elements unique to immersive VR and an evidence-based educational paradigm in mind. Hence, the design of the environment to enhance the study of 3D transformations in computer graphics is presented, employing the principles of CTML. Educational theory should provide the framework and foundation for creating efficient interventions. The immersive VR learning environment will also be shown in this paper, along with its development and first evaluation.

2 Background

The development of virtual reality technology in recent years has created new possibilities for immersive learning experiences. VR has been shown to improve learning [8, 9]. Only a minority who concentrate on design have adopted a particular learning theory as a guide for developing VR tools technically [19]. Two hypotheses drive our environment development process. As texts and visuals are presented together in virtual environments, we first define VR as a multimodal educational tool. Second, acquiring knowledge is a dynamic process involving more than memorizing facts or critical ideas. As a result, we follow Mayer's meaningful learning hypothesis [6]. This learning approach emphasizes the active construction of knowledge and using the information to comprehend new ideas, solve difficulties, and transfer that knowledge to new learning scenarios [6]. Mayer suggests designing educational materials using the CTML's guiding principles for the purpose of facilitating meaningful learning [10]. Our environment has developed based on the direction of these two assumptions. In order to assist students in learning through multimedia education, we first present the CTML, explain how multimedia learning functions, and discuss the implications for instructional design. The essential characteristics of immersive VR technology will next be discussed. To inform the design of the VR environment, we integrate immersive VR features with CTML.

2.1 Learning with Multimedia

Multimedia learning involves a combination of written or spoken words with animated or static pictures for educational purposes [11]. This concept, which comes from Mayer and colleagues' empirical work, is widely used and has an impact on studies on several kinds of educational media, including video, computer games, simulations, and immersive VR. The theoretical framework for how individuals learn through multimedia instructional messages is called the CTML [10]. The CTML is based on three assumptions. The first assumption is that dual-channel is that humans use two distinct channels to process information. Verbal information is processed through an auditory channel, and visual information is processed through a visual/pictorial channel [10]. The second principle is that humans have a limited capacity to simultaneously process information in each channel, based on the results of cognitive load theory. The basic idea of this theory is that depending on the type of information we receive during the process of learning, it leads to one of three various kinds of processing that occur in the brain. To lead the learner's appropriate cognitive operations without overloading their working memory, instructional designers must overcome these challenges. In light of the fact that our ability for real-time information processing is limited, to ensure the greatest possible retention in long-term memory, the goal for educators should be to create multimedia that controls essential processing and optimizes generative processing while minimizing extraneous processing. Active processing is the third constructivist concept added to the above two cognitivist principles. Humans construct coherent mental representations by selecting pertinent information, paying attention to it when it comes in, and combining it with existing knowledge. This is known as active learning. In short, people learn through multimedia when they generate mental representations from images and words to incorporate new information into existing knowledge after processing it. By undertaking this process, the possibility that the knowledge will be stored in long-term memory is improved [12]. According to the CTML's guiding principles, learning with multimedia instructional messages is then what Mayer refers to as meaningful learning, in which students gain knowledge and abilities to solve problems effectively [6]. Empirical studies have consistently validated the CTML's underlying assumptions over the years. Three main objectives for instructional design were identified from these findings, and they should be taken into account while creating environments for multimedia learning [10].

2.2 Design Objectives for Instruction

The objectives of instructional design stem from the scientific investigation into effective methods of facilitating learning, known as the science of instruction. The prevailing belief is that meaningful learning cannot be facilitated just by hands-on activities but that active processing under cognitive guidance can [11]. Three instructional design objectives are crucial to assisting learners in learning with multimedia instructional messages while considering the CTML principles: The first design objective is to minimize extraneous processing [10]. This is the elimination of distracting elements from the multimedia educational setting, such as the redundancy principle's combining spoken and written words or the coherence principle's playing background music. Information can also be shown in a synchronized manner in both temporal and spatial terms. Meta-analysis also supports the beneficial effects of the spatial and temporal contiguity principle on the results of learning [13]. The signaling principle similarly involves the utilization of colours and symbols to direct the learner's focus toward pertinent content. By reducing the cognitive load involved in finding pertinent information, signaling aids in helping learners concentrate on important concepts.

In order to prevent cognitive overload, the second design objective of scaffolding is to assist learners in managing the essential processing, additionally referred to as intrinsic load. These principles that assist are the segmenting principle, pre-training, and modality principles. Research pertaining to the segmenting principle suggests that difficult content be divided into smaller modules to avoid cognitive overload as well as promote efficient learning. Before starting multimedia messages, pre-training aims to assist students build the necessary prior knowledge and scaffold their learning. In this approach, learners first familiarize themselves with the fundamental concepts of a lesson before engaging with multimedia messages. This sequence allows for allocating working memory resources to essential processing tasks. The modality principle, which suggests that instructors utilize narrative rather than on-screen text when there are pictures, is partially influenced by assumptions of dual-channel and limited capacity. At least for less difficult topics, this presentation form improves learning.

The third objective of instructional design is to use generative processing to make sense of the content. Applying generative learning techniques and social cues is advised in this case. The personalization principle states that social cues include using colloquial language in narration. The voice principle is that multimedia learning environments use human voice instead of computer voice to provide spoken content. Drawing principle and self-explanatory are examples of generative learning techniques for multimedia learning. The utilization of learning techniques is grounded in the concept that learning involves an active process of constructing knowledge. The beneficial impact of such strategies has already been demonstrated in the context of educational videos. With the use of strategies, watching videos can be turned from a totally passive form of consumption into an active interaction with the material [14]. The stated instruction objectives are intended to assist students in acquiring information and abilities that they may use when faced with new challenges and assignments.

2.3 Important Characteristics of VR Technology

The immersion VR learning environments necessitate a deep grasp of the medium and the variables influencing users' perceptions of the technology to apply instructional objectives and multimedia principles correctly. The definition of VR is "Virtual Reality mostly can be defined as a virtual object in virtual Environment" [15]. In contrast to other reality-enhancing technologies like augmented virtuality and augmented reality, this sets virtual reality apart.

Realistic three-dimensional visualization of data is made possible by VR learning environments, particularly the more immersive ones, which also provide an engaging, real-time educational experience. By offering a unique and efficient method of learning and motivating learners, they can enhance performance results, facilitate high levels of interaction with objects and people, enable the presentation of a virtual setting that mimics the real world, and promote conceptual comprehension [16]. Based on this technology, learning environments enable true learning experiences that other media, like videos, are unable to deliver in an appropriate manner. Opinions vary regarding what makes VR unique from other forms of instructional media. The two most significant and generally acknowledged primary characteristics of VR are immersion and interaction [17]. The concept of immersion is user involvement in a VR experience that puts them in a state of flow. The term "immersion" objectively describes the technical features of a VR system, outlining the extent to which users feel deeply engaged and involved in the simulated environment [18]. Simply put, it refers to the feeling that you are fully immersed in the virtual environment and that everything is real. The other feature of VR that can potentially create an immersive experience is interaction, which allows the system to recognize user input signals and react instantly [17]. The interaction in VR refers to the ability of users to engage with and manipulate virtual objects and worlds in real-time. Because of this feature, users can engage with the virtual environment through various input techniques, including gestures, hand tracking, or portable controllers. This enhances the VR experience, making it more captivating and interactive for users. For example, in a virtual classroom where the users are surrounded by digital representations of textbooks, whiteboards, and desks, this feeling is immersion. Using a controller, you pick up a virtual pen and start writing on the digital whiteboard this is interaction.

3 Design of Immersive VR Learning Environment

We incorporate the principles of CTML, instructional design objectives aimed at facilitating learning, and the fundamental characteristics of Immersive VR technology. As a result, we built a meaningful immersive VR learning environment to learn 3D transformations in computer graphics. The conceptual framework that guided the construction of the immersive VR environment helps to control intrinsic load and optimize germane load while minimizing extraneous load. According to Richard Mayer's theory, successful learning experiences are facilitated by multimedia messages and cognitive processing.

Visual information presentation has been shown to improve learning, according to CTML. In the VR environment, we provided visual demonstrations of 3D transformations using interactive 3D shapes while providing accompanying textual explanations for transform functions and OpenGL code. For example, as users manipulate a rectangle in the VR environment to perform transformations like rotation, they receive simultaneous visual explanations of the actions, including the rotation angle they apply, and corresponding real-time feedback on how the rectangle rotates in response to their manipulations. Information is better understood when presented in visual and auditory formats. In our environment, users can interact directly with virtual objects, prioritizing visual representations of 3D transformations in line with the modality principle. By physically manipulating 3D shapes using VR controllers, users experience the effects of various transformations. Furthermore, the boundary conditions of the modality principle suggest that printed words may be appropriate in lessons containing technical terminology and symbols [22]. Therefore, we display on-screen text for OpenGL commands without narration in our VR setting. We achieved coherence by designing intuitive user interfaces and minimizing distractions within the VR environment. For example, providing users with information that supports learning goals with simple controls and clear instructions to perform 3D transformations without overwhelming them with unnecessary information. For the purpose of reinforcing the spatial contiguity principle—the relationship between acts and their results—we placed text and dynamic images spatially. To improve comprehension and lessen cognitive strain, users can choose a scaling function, for instance, and then see pertinent instructions and visual feedback in close proximity to the outcome. We offered users the option to receive a textual explanation alongside visual elements to understand the visual representation of the 3D transformation functions and OpenGL commands. This redundancy ensures that users have multiple opportunities to grasp these concepts. For the purpose of managing necessary processing in immersive VR, it is also advantageous to break down difficult tasks into segments. Also, we broke the concept up into more manageable, smaller pieces. Each segment focused on one aspect of 3D transformations, such as rotating around different axes, translating objects along specific paths, or scaling objects uniformly or non-uniformly. This keeps learners from experiencing cognitive overload and enables them to concentrate on one idea at a time. The immersive VR environment has clear navigation and structure to guide learners through the segmented learning process with VR controllers; this principle improves learning effectiveness and retention. By applying these CTML guiding principles, we designed an immersive VR environment that effectively facilitates learning 3D transformations. This VR experience provides users with interactive and intuitive ways to explore and understand complex visual representations and OpenGL codes in a virtual environment.

4 Immersive Environment Development and Evaluation

The Unity game engine created the VR setting, and C# was used as the programming language. The HTC Vive Pro is a completely immersive virtual reality headset that we utilized as a Head-mounted display (HMD). In the development of our VR environment, we aimed to create an immersive platform that enables users to apply various types of 3D transformations within a 3D Cartesian coordinate system. These transformations include translation, rotation, and scaling. User interaction within the VR environment is facilitated through VR controllers, which serve as the primary interface for navigating and manipulating objects. Upon entering the scene, users are presented with a control panel that allows them to select an object and choose a transform function (see Fig. 1). This control panel provides options for entering specific X, Y, and Z values for the transformation or selecting preset values. Real-time feedback is a crucial aspect of the user experience, and our VR environment reflects applied transformations instantly within the scene. Users can observe the effects of their actions as objects undergo transformations, allowing for immediate visual feedback and validation of the desired outcome. Furthermore, to enhance understanding and visualization of transformations, each object shape within the scene is labeled with a colour and its face name. This labeling scheme provides users with clear visual cues regarding the identity and orientation of objects as they undergo transformations. The VR environment also supports user mobility, allowing them to walk and explore the virtual space freely. Users can move their heads around to view objects from different angles, enhancing their spatial awareness and understanding of the scene. Additionally, users have the option to fly around and walk faster using VR controllers, providing them with greater control and flexibility in navigating the environment. To aid in the comprehension of transformations a 3D projections of objects in the system plane, enabling users to visualize how objects are transformed relative to the coordinate system. Additionally, OpenGL commands are displayed to provide users with insight into the underlying rendering processes and transformations applied within the system and help to understand visual representations. Overall, our developed VR environment offers a comprehensive and intuitive platform for applying and visualizing basic 3D transformations, empowering users to gain deeper insights into spatial manipulation for objects within the scene. We conducted a formal pilot study with participants experienced in computer graphics and VR. The goal of this study was to test a VR environment designed according to CTML principles to explore usability and user experience, supporting effective learning of 3D transformations. We evaluated how easily users can navigate and interact within the environment, assessing their satisfaction and engagement levels through a VR learning experience for understanding 3D transformations using a questionnaire. The study's findings were encouraging, revealing that users found it easy to learn OpenGL commands in this context due to the environment providing a visual representation of what they are learning. We employed a qualitative approach involving thematic analysis of user feedback and observations, from which we obtained valuable feedback and suggestions to improve the environment.

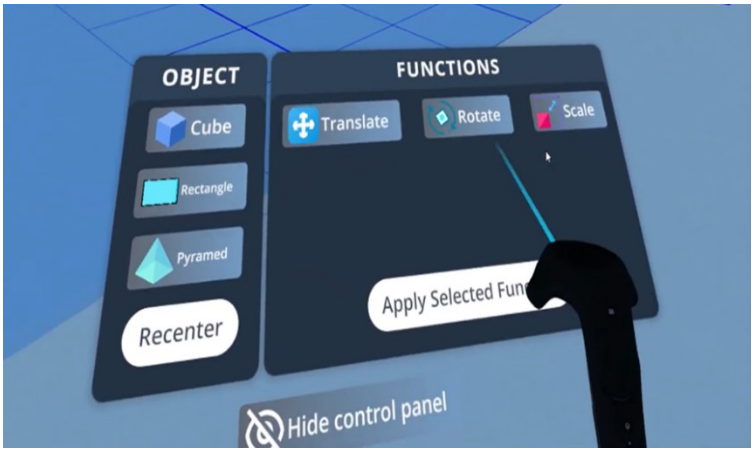

Fig. 1. Objects and three main functions in the VR environment.

5 Discussion and Conclusion

In this paper, we have introduced an educational VR environment designed to enhance the learning of 3D transformations in computer graphics. By adhering to the principles of CTML, the environment was crafted to facilitate information processing and minimize cognitive strain, thereby fostering learning outcomes. The initial evaluation through a pilot study yielded promising results, indicating that the VR environment contributes positively to the learning process. However, as with any development, usability issues and areas for enhancement were identified during the evaluation phase. One prominent issue highlighted by users was the size of the control panel; they found it to be too large, which hindered their ability to see and interact with the rest of the user interface effectively. Additionally, users found the rotation confusing, particularly discerning whether objects were rotating clockwise or counterclockwise. Furthermore significant usability concern was related to the movement mechanics using VR controllers. Users reported that the movement felt inconvenient and unnatural, detracting from their immersion and making it challenging to navigate within the virtual space effectively. Another notable issue was the absence of decimal points for scaling objects, making it challenging for users to manipulate object sizes accurately. To address these usability issues and enhance the VR environment, several improvements are proposed. Firstly, scaling down the control panel to a more manageable size will be implemented to improve visibility and reduce obstruction. Secondly, introducing visual cues or symbols to indicate the direction aids users in understanding the direction of rotation. Moreover, adjustments will be made to the movement mechanics to make them feel more natural to users. Finally, including a feature to input decimal points for scaling down objects will enhance precision and ease of understanding for users. In addition, enhancements will be made to the overall environment to reduce limitations. For instance, the projection will be refined to enhance the perception of 3D transformations by adjusting lighting and shadow effects. Furthermore, implementing a trace feature to demonstrate how objects move, scale, or rotate visually will provide users with assistance in understanding spatial transformations before applying any transformation function. Additionally, relocating the user to negative coordinates within the environment will offer a more comprehensive learning experience. The study results indicate that visualizing 3D transformations is highly engaging, and the swift feedback on transformations, along with natural interaction with the user interface, holds potential implications to enhance learning and spatial understanding. Overall, our environment represents a valuable tool for understanding the fundamental concepts of 3D transformations, visual representations, and OpenGL codes (see Fig. 2). Future work will on enhancing the VR setting and refining the prototype based on feedback. Moving forward, we plan to conduct a comprehensive study to explore and validate the effectiveness of immersive VR in facilitating learning of 3D transformations and its impact on users' spatial skills.

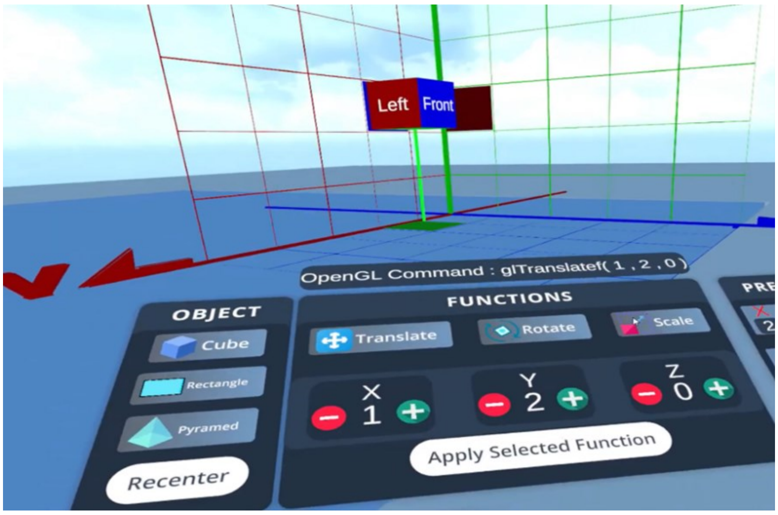

Fig. 2. The visual representation and OpenGL command of translation (1, 2, 0).

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