23. The Effect of Virtual Stereoscopic Displays on Learning

MEREDITH THOMPSON, CIGDEM UZ BILGIN, M. SHANE TUTWILER, MELAT ANTENEH, JOSEPHINE MEIJA, RIK EBERHART, PHILIP TAN, DAN ROY, JUDY PERRY, AND ERIC KLOPFER

Abstract: Three-dimensional immersive visualizations may help students develop more expert ideas, as long as visualizations are properly scaffolded for learners. In this study, we examined how a dynamic virtual reality (VR) visualization influenced players' ability to understand the cellular environment and cellular processes by comparing learning from a virtual reality game on cellular biology between a stereoscopic (head-mounted display, or HMD) with a nonstereoscopic (non-HMD) alternative. Participants in both groups gained a better understanding of the cellular environment; however, participants who viewed the stereoscopic game had greater learning gains than the nonstereoscopic group. In addition to investigating the impact of VR in learning, we also explore how to scaffold educational VR games to optimize learning.

Background

The relationship between structure, mechanism, and function is critical in understanding biology (Michael & McFarland, 2011), yet students often have a limited understanding of the connections between them. Research suggests that the realism of virtual reality (VR)-based stereoscopic visual representations may help novices develop more accurate mental models than nonstereoscopic displays (Ferdig, Blank, Kratcoski, & Clements, 2015). The increased accessibility and decreased cost of VR make VR more feasible for educational settings, and VR experiences have been developed to explore structural aspects of biology and biochemistry. However, existing studies of learning through VR show mixed results. Many studies of VR conflate the contributions of VR by varying both the viewpoint and the level of interactivity of the experience (slidedeck to interactive experience, e.g., Parong & Mayer, 2018). In order to isolate the effect of the VR-based display, we compare two similarly interactive stimuli (Gauthier & Jenkinson, 2017), varying only the viewpoint. This study is designed to focus on the effect of the stereoscopic view enabled by the head-mounted display (HMD) by having players play identical versions of a game with and without the HMD. Our research question is: "What effect does a stereoscopic view have on players' understanding of the complex cellular environment compared to a nonstereoscopic view?"

Theory of Multimedia Learning

The theory of multimedia learning (Mayer & Fiorella, 2014) states that the brain processes text and images first separately (dual coding theory), that each channel has limited capacity (similar to cognitive load theory), and that learning is the process of bringing the information together and making sense of it. According to this theory, the goal of multimedia design is to limit extraneous processing that is not related to the learning objective, manage the essential processing, and foster generative processing (sense making). In the case of virtual reality, learners typically experience significantly higher cognitive load and learn less in comparison to those who do not use VR (Makransky, Terkildsen, & Mayer, 2019). The increased amount of sensory information in both the visual and verbal channels can cause learners to experience essential processing overload in VR compared to a less immersive counterpart (Richards & Taylor, 2015). In order to combat cognitive load, Mayer and Moreno propose a variety of solutions depending on the kind of load.

In previous studies, VR has been an overload on either or both of the visual and verbal channels. The suggested load-reducing methods are off-loading, segmenting, and pretraining (Mayer & Moreno, 2003).

Stereoscopic Displays and Learning

Studies show that students prefer three-dimensional (3D) views of material over two-dimensional (2D) views (Ferdig et al., 2015; Huk, Steinke, & Floto, 2010; Loup-Escande, Jamet, Ragot, Erhel, & Michinov, 2017). Studies were mixed on the effects of the view of learning. Ferdig et al. (2015) found that 3D images were correlated with higher quiz scores on high school students' tests on the brain and the first anatomy unit, but not on a second anatomy unit. Huk et al. (2010) found that cues had a positive effect on students' recall and comprehension of ATP-synthase for both the 3D and 2D groups. The 3D group had a better understanding of how ATP-synthase worked in the laboratory condition, but not in the classroom setting, suggesting that distractions in the classroom setting may create additional cognitive load on the students. Loup-Escande et al. (2017) focused on stereoscopic versus nonstereoscopic views in educational virtual environments by having students play different versions of the game *VirtualKart2*. The participants who had the 3D view were more likely to complete the game successfully and experienced more immersion and flow during the game, but that there was no difference between 2D and 3D in learning outcomes.

Experience in an immersive 3D environment may also impact learners' gains from the game. In a study of the effect of nonstereoscopic 3D and stereoscopic 3D images on immediate, delayed, productive, and receptive recall of foreign language vocabulary, Kaplan-Rakwoski (2019) found no significant difference between the effect of stereoscopic 3D and nonstereoscopic 3D images on foreign language recall for both immediate and delayed test scores; however, there was a significant difference in receptive recall for learners who reported not having played a stereoscopic 3D video game before the study. The level of interaction with the material may also impact learning. Remmele, Weiers, and Martens (2015) compared the effect of 2D and stereoscopic 3D visualizations on students' understanding of the nasal cavity. Students who used the 3D visualizations were more likely to represent details in their clay-based models. When both 2D and 3D groups were asked to interact with the model by turning the virtual model, they found the 2D model also helped students understand spatial depth. The number of studies focusing on learning outcomes is still relatively small (Loup-Escande et al., 2017); thus additional research is needed to best understand the different views.

Cellverse

This study investigates an educational game designed to help students learn cellular biology called *Cellverse*. The goal of the game is to explore, diagnose, and select a therapy for a virtual cell. The diseases they investigate have a genetic component, leading players to interrogate cell processes, especially the central dogma (DNA to RNA to proteins). When players first enter the virtual cell, they are in a projection of the cell, which is a simpler environment with fewer organelles. Players are introduced to FR3ND, a nonplayer character (NPC) who accompanies the player during the game. FR3ND shows players features of the hand controllers, including how to move forward, how to select organelles, and how to call up a virtual clipboard to learn about and collect samples of the organelles, as shown in Figure 1 (left), and how to bring up a dashboard guide, as shown in Figure 1 (right). Once players complete the tutorial, they start the inquiry and are given a checklist at the bottom of the dashboard: first to look for clues, gather evidence based on those clues, and verify that evidence. In addition to traversing across the cell at microscale, players can also launch a nanobot and see a view of the process of translation from messenger RNA (mRNA) to amino acid chains through ribosomes at the rough endoplasmic reticulum (RER). As in microscale, players can look for clues and gather evidence. The evidence they gather appears in the right-hand column of the dashboard, as shown in Figure 1 (right). After players verify their evidence, they can then use the evidence to make a diagnosis of one of the five types of cystic fibrosis in the cell.

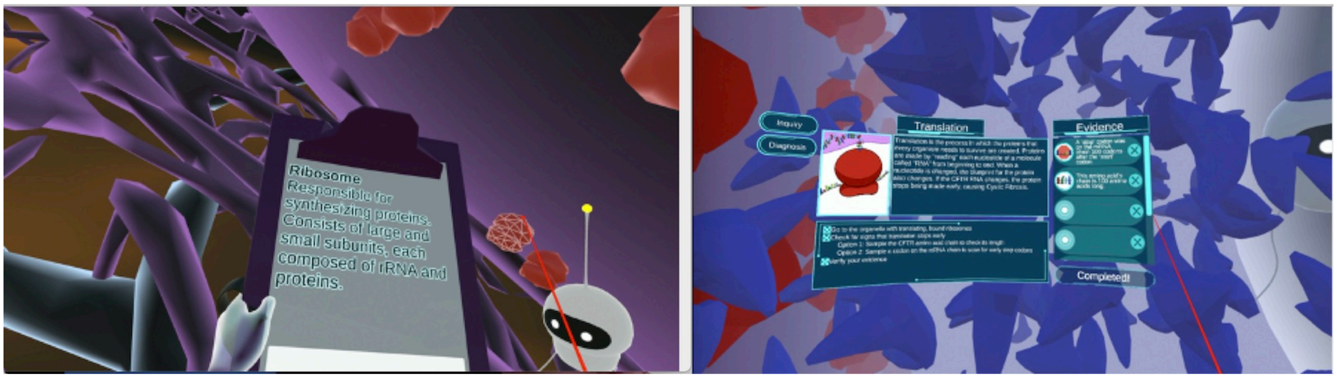

Figure 1. The microscale view in Cellverse shows the nonplayer character FR3ND and the clipboard (on left). The nanoscale view in Cellverse shows dashboard (on right).

Initial studies of an open-ended version of the game show that students gain more accurate overall mental models of the cell but did not improve in their understanding of size and scale or in their factual knowledge of cell organelles (Thompson et al., under review). This inquiry focuses on the role of the stereoscopic view in learning about the cellular environment.

Method

Data collection for the study occurred between February and March of 2020. Our initial plan was to recruit 100 adult participants with varying ages and biology background (50 per group) and randomly assign them to one of the two study conditions. Because of the COVID-19 pandemic, our data collection stopped at 60 participants, and we received completed data from only 51 participants. Participants were randomly assigned to one of two versions of the 3D game: an HMD version and a non-HMD version. Participants took assessments of biology knowledge (pre- and post-gameplay) and answered demographic questions and background questions about game experience, VR experience, biology experience, and self-described interest in science (pre-gameplay only). Participants completed a delayed postassessment one week after their game session. Participants who completed all parts of the study were emailed a $20 egift card to Amazon.com. Participants also answered questions about mental workload and spatial awareness of the cell; however, those questions will be analyzed separately and will not be addressed in this paper.

Sample

Participants were 51 adults with different nationalities including American, Chinese, Estonian, French, Indian, Israeli, Italian, Spanish, Taiwanese, Ukrainian, and Zambian. Their ages ranged from 18 to 65 years old (M = 26). Participants' other demographic information, including gender, VR experience, gameplay experience, and ethnicity are shown in Table 1); 71% reported that they had VR experience only once, and 37% identified as gameplayers. Participants were from different ethnicities and mostly they identified as Asian and White.

Gender, frequency (f), percent (%)		VR Experience, f, (%)	
Female	31 (61%)	Yes-many times	7 (14%)
Male	19 (37%)	Yes-only once	36 (71%)
Other	1 (2%)	No	8 (16%)
Game Player, f (%)		Ethnicity, f (%)	
Definitely yes	19 (37%)	Asian	18 (36%)
Probably yes	13 (26%)	Black-African American	4 (8%)
Might or might not	8 (16%)	Hispanic-Latino	10 (20%)
Probably not	6 (12%)	White	17 (33%)
Definitely not	5 (10%)	Prefer not to answer	2 (4%)

Table 1. Demographics and game and VR experience among study participants.

Analysis

Our research question is: "What effect does a stereoscopic view have on players' understanding of the complex cellular environment compared to a nonstereoscopic view?" We initially intended to answer that research question in two ways: through responses in the pre- and postsurveys assessing participants' knowledge of cells, and through reviewing participants' pre- and post- drawings of cells and their pre- and post- drawings of the process of translation. However, our data collection was disrupted by the pandemic. For this paper, we will focus on a comparison between participants' pre- and post- drawings of cells and their pre- and post- drawings of translation.

Drawings of Cells With and Without HMD

Participants' drawings of cells and translation are our evidence of players' understanding of the complex cellular environment. As mentioned previously, participants were asked to draw a cell before and after gameplay, and to include and label all organelles. The presence of any of those items in the drawing received a score of 1, and scores of all items were combined for an overall drawing score.

Number of Organelles in Post- Drawings

The total number of labeled organelles in the drawings from participants who had the stereoscopic condition (n = 181) is slightly higher than the nonstereoscopic condition (n = 165) in post- drawings of cells. As shown in Figure 2, cell membrane, rough ER, and lysosomes are the organelles that are most often drawn and labeled in the post- diagrams. As is clear from the bar chart, participants' total number of labeled organelles in both conditions are very similar.

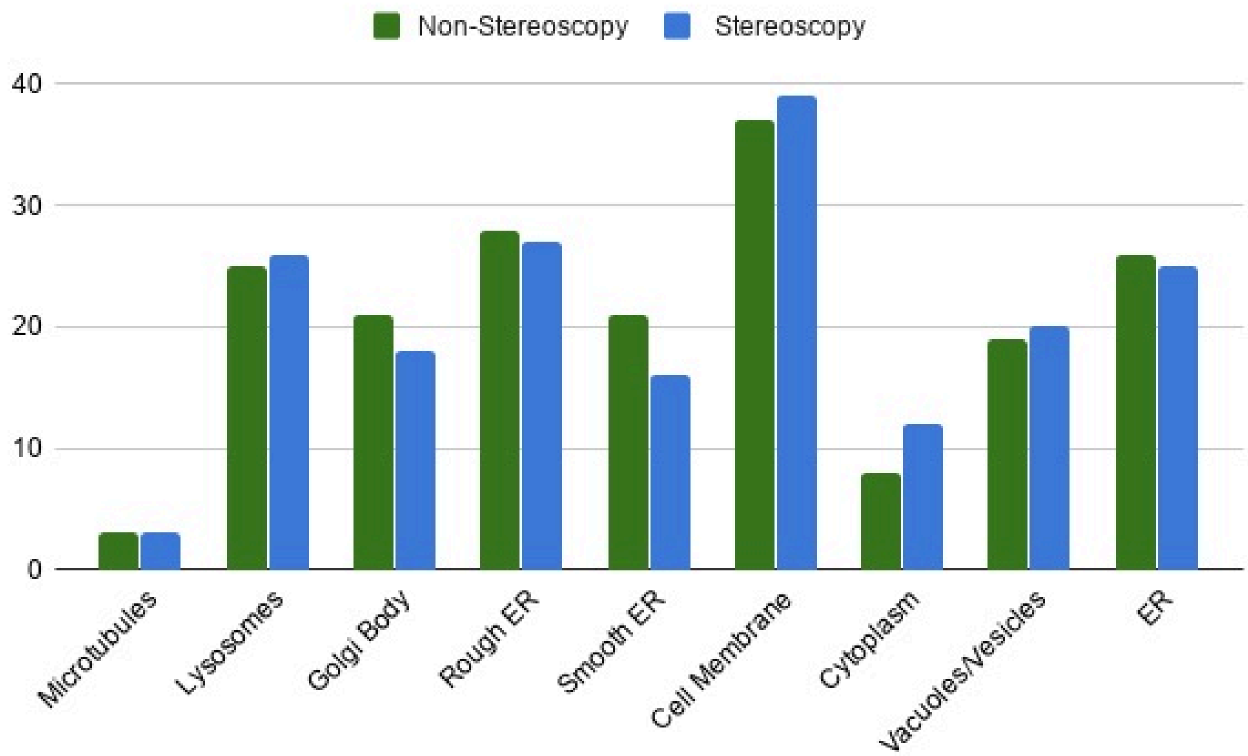

Figure 2. Total number of organelles drawn in stereoscopic and nonstereoscopic conditions.

We also compared the drawings before and after gameplay. As shown in Figure 3, the post- total number of labeled organelles is slightly higher than the pre- total number of labeled organelles in both the stereoscopic condition (pre- labeled organelles [MD: 5.00, CI: 4.23 ~ 6.27], post- labeled organelles [MD: 8.00, CI: 5.30 ~ 7.63]) and the nonstereoscopic condition (pre- labeled organelles [MD: 6.00, CI: 5.12 ~ 7.44], post- labeled organelles [MD: 8.00, CI: 5.10 ~ 8.10]).

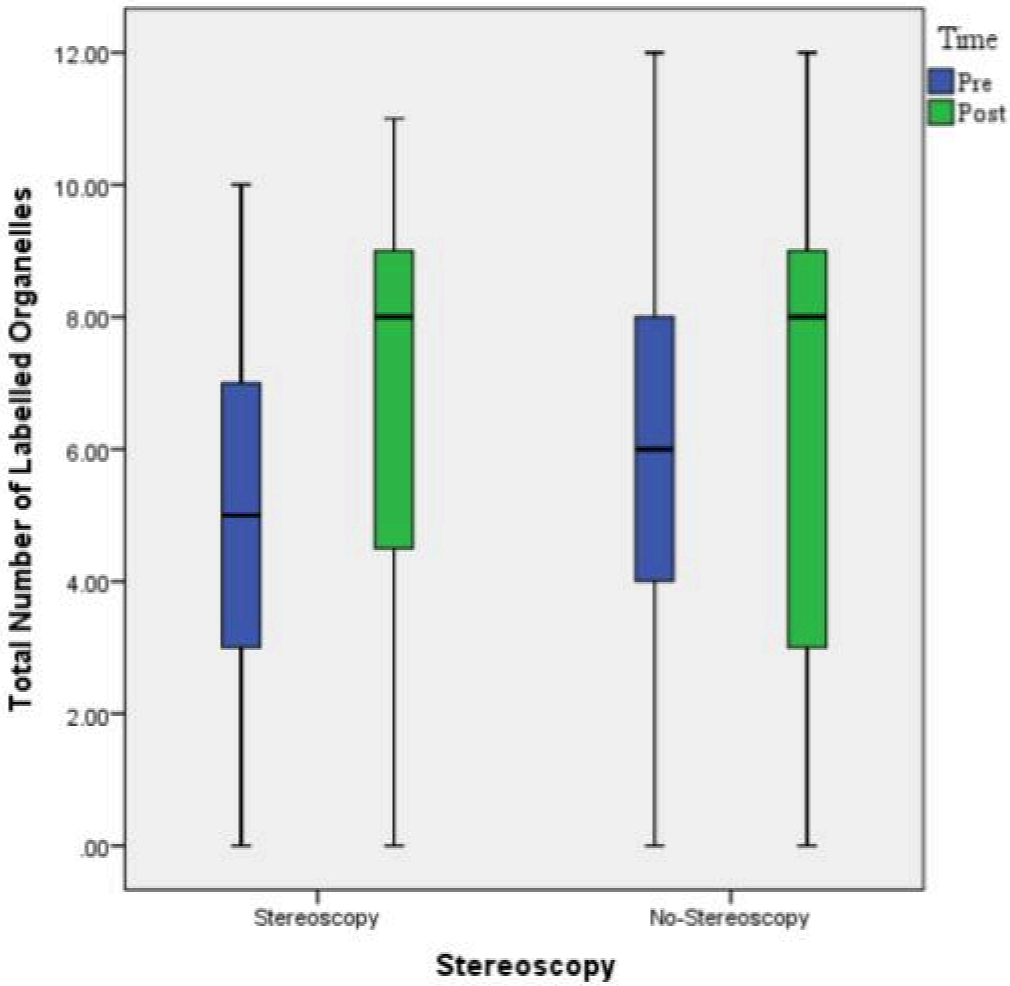

Figure 3. Comparison of number of organelles in pre- and post- drawings between stereoscopic and nonstereoscopic views.

Discussion

The decreasing cost of virtual reality technology has prompted additional interest in VR as a learning tool. The stereoscopic viewpoint offered by VR HMDs is motivating to viewers and has shown promise in developing spatial awareness and understanding. This study focused on knowledge of the cellular environment as evidenced through their pre- and post- drawings of cells. Our findings suggest that the learning game provided gains for all players. We did not find any difference in learning gains between stereoscopic and nonstereoscopic displays, suggesting that knowledge of organelles and the density of the cellular environment can be gained with or without an immersive view of the material. We are also comparing the effect of stereoscopic versus nonstereoscopic viewpoints on understanding of cellular process of translation, mental workload, and spatial awareness of the cell, and we will address these analyses in separate papers.

Contribution to the Field

Immersive visualizations afforded by VR have the potential to help learners develop better understanding of complex topics. This study focuses on the role of stereoscopic visualization in biology; however, learning how to leverage technology in support of learning has the potential to inform future curricula in biology and in other domains. As VR becomes more feasible as a learning tool, additional research will be needed to understand whether VR is effective and if so, how it is best integrated into educational experiences.

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