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Processing Presence: How Users Develop Spatial Presence through an Immersive Virtual Reality Game

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Abstract
A primary affordance of virtual reality (VR) headsets is to give the user spatial presence, or the illusion of being in the virtual environment. Although considerable research connects VR to spatial presence, spatial awareness, and spatial ability, little is known about how users develop spatial presence in VR learning environments. This study addresses that gap by exploring spatial presence experience construction in a virtual reality (VR) educational game and investigating whether users' knowledge, game experience, and VR experience impact the establishment of spatial presence. In this study, 56 high school students played an immersive 3D VR cell biology game where players search for clues within a virtual cell to diagnose the cell. Findings suggest that players' perceptions of spatial presence are linked to how they allocate their attention during the game, their level of interest in cellular biology, and their visual-spatial acuity, but are not linked to their game experience, VR experience, or prior knowledge of the content area. These results indicate that well-scaffolded, engaging virtual environments can foster spatial presence among users, regardless of prior knowledge or experience, and gives practitioners clues about how to design VR learning environments.

Keywords: Virtual Reality, Immersive Technology, Game Based Learning, Spatial Presence, Learner Characteristics, Spatial Ability

Declarations

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Consent for publication: All authors consent to the publication of the manuscript in Virtual Reality Journal.

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Abstract

A primary affordance of virtual reality (VR) headsets is to give the user spatial presence, or the illusion of being in the virtual environment. Although considerable research connects VR to spatial presence, spatial awareness, and spatial ability, little is known about how users develop spatial presence in VR learning environments. This study addresses that gap by exploring spatial presence experience construction in a virtual reality (VR) educational game and investigating whether users' knowledge, game experience, and VR experience impact the establishment of spatial presence. In this study, 56 high school students played an immersive 3D VR cell biology game where players search for clues within a virtual cell to diagnose the cell. Findings suggest that players' perceptions of spatial presence are linked to how they allocate their attention during the game, their level of interest in cellular biology, and their visual-spatial acuity, but are not linked to their game experience, VR experience, or prior knowledge of the content area. These results indicate that well-scaffolded, engaging virtual environments can foster spatial presence among users, regardless of prior knowledge or experience, and gives practitioners clues about how to design VR learning environments.

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Introduction

Recent technological advancements in mediated environments have enabled the development and exploration of virtual spatial presence (Khenak et al., 2019). Spatial presence is a feeling of feeling that you are physically present in a virtual environment (Weibel & Wissmath, 2011) even though you are in a different physical environment (Witmer & Sigmer, 1993). Computer generated environments evoke a specific type of presence: virtual spatial presence (Lessiter et al., 2001), and designers have created immersive technologies to increase the experience of virtual spatial presence (Cummings & Bailenson, 2015). For this paper, we will refer to virtual spatial presence as spatial presence. Defined as a "technology that surrounds individuals with an immersive artificial environment" (Gillath et al., 2008, p. 260), virtual reality (VR) technology has a history dating back to the mid-20th century (Wang, 2020), but has become increasingly popular in various disciplines since the late 1980s and early 1990s (Seibert & Shafer, 2018). VR environments are evaluated in part by the level of spatial presence felt by the user while in the environment, thus one of the designing goals of VR environments is increasing the user's perception of being in the environment (Hedge et al., 2017; Hounsel et al., 2013). Current research has explored spatial presence experiences in various VR platforms including learning environments (Cheng & Tsai, 2019), games (Larkin, 2015; Seibert & Shafer, 2017), and spatial knowledge tasks (Parong et al., 2020). The models and questionnaires developed to test spatial presence experience often include the following factors: feeling of being there, being aware of actions, focus, attention, involvement, sensing the environment as real, and feeing isolated from the real environment (Wirth et al., 2007, Witmer & Singer, 1998, Lessiter et al., 2006). Some models also include user characteristics including spatial ability and content interest, which are not directly related to the experience in the mediated environment (Wirth et al., 2007, Lessiter et al., 2006).

Although research on learning experiences in VR environments continues to develop rapidly, much of the research on spatial presence draws from theoretical models of spatial presence developed 15-20 years ago (Cheng & Tsai, 2019; Parong et al., 2020). As the characteristics of VR environments are changing (using head-mounted displays, increasing stereoscopy, more interaction with hand controllers, etc.), models have to be tested and validated to account for those changes. Wirth's et al. (2007) model has been used extensively in other studies, thus, it is a good starting point to explore how innovations in VR might impact presence. Moreover, a recent study found that the spatial presence questionnaire developed based on Wirth et al.'s (2007) model is the one most sensitive to immersive technologies (Yildirim et al., 2019). Studies also show that different user characteristics might take role in different platforms (Sacau et al., 2007; Larkin, 2015). In this respect, this study uses the Spatial Presence Model (Wirth et al., 2007) to explore the development of spatial presence among players of an immersive VR learning game when accounting for the players' prior knowledge of the topic, game experience, and VR experience.

Literature Review

Spatial Presence Models

According to the proposed spatial presence model (Wirth et al. 2007), spatial presence is a two-dimensional construct that is the combination of user`s *perceived self-location* (sense of being in there) and *perceived possible actions* (being aware of how they can interact with the environment). Wirth et al. (2007) claim that spatial presence is established and maintained through the players' formation of the model of the environment ("spatial situation model", or SSM) through viewing the environment from an ego-centered perspective (Wirth et al,, 2007). According to this model, the first phase (creating the model) can be enhanced by drawing attention to the mediated environment. Attention is guided in two ways: through media-related features (external factors) that direct users' attention to the stimulus, and through the players' personal interest in the topic of the game (Wirth et al., 2007, Wirth et al., 2003). The other factor that affects the user's mental model of the environment is the user's spatial abilities. Wirth's model proposed that each individual's visual spatial imagery ability significantly affects the SSM and spatial presence as well. In the second phase, suspension of disbelief and higher cognitive involvement strengthen forming ego-centered perspectives of the virtual environment, which is the foundation of the experience of spatial presence. Vorderer et al. (2004) proposed questionnaires to test the spatial presence model; other researchers tested and verified the model across different platforms (Hofer et al., 2012, Wirth et al., 2003).

According to Witmer and Singer's spatial presence model (1998), the experience of spatial presence is constructed through the user's level of involvement and immersion. Involvement depends on how users draw their attention to the mediated environment. Witmer and Singer developed a spatial presence questionnaire including the following items about the mediated environment: providing control on tasks, increasing sensory information to the related sensors, isolating users from the physical environment, engaging the user so their attention is not diverted to distractions that come from their real/physical environment, and providing realistic and meaningful experiences (Witmer & Singer, 1998). Although some parts of this questionnaire and Wirth et al. (2007)'s model overlap (for instance, triggering attention to the mediated environment and controlling on tasks), Witmer & Singer (1998) could not find any association between spatial presence experience and spatial ability, which is an integrated part of Wirth et al. (2007)'s model. Lessiter et al. (2006) developed a questionnaire to test spatial presence experiences with items to learn users' sense of location in the environment, how naturalistic users find the stimulus, users' sense of involvement, content interest and attention to the environment, how much users sense the environment as real, and negative effects (feeling dizzy etc.) of viewing the environment. Although these models and questionnaires include similar items, their sensitivity might be different in various platforms (Yildirim et al., 2019). Yildirim et al. (2019) compared three different spatial presence experience questionnaires in order to test perceptions of presence in three different platforms: 360 video, 3D animation, and an interactive 3D game. The social realism factor of the Temple Presence Inventory Lombard et al., 2011) and possible actions dimension of MEC spatial presence questionnaire (Wirth et al., 2007) were sensitive to different VR platforms, but ITC-sense of presence inventory (Lessiter et al., 2001) was not sensitive across different platforms. Recent studies have shown that user abilities and characteristics might have an impact on their experience of spatial presence (Larkin, 2015; Coxon et al., 2016).

User Characteristics and Spatial Presence

Wirth et al. (2007) claimed that domain interest and spatial visual imagery are the primary factors that have an impact on how users build SSM as well as spatial presence. Sacau et al. (2007) studied spatial presence among users of a 3D computer game where participants used a computer mouse to visit many rooms in a temple. They found an association between spatial presence and user characteristics including degree of absorption, domain interest, and agreeableness, but they did not find any association between spatial presence and spatial visual imagery. The association between spatial presence and domain interest was only found in hypertext, film, and virtual environment stimulus, but not in linear text stimulus, which is media with the lowest degree of immersion. In a recent study, Coxon et al. (2016) explored the association between users' visio-spatial imagery, mental rotation ability, and topographical memory in a VR environment viewed through a head-mounted display (HMD). Their game was a Xbox console game played with a joystick where users can interact with other game characters to collect information and clues in a VR environment. They found a significant relationship between spatial presence and visio-spatial imagery, but not between spatial presence and either mental rotation ability or topographical memory. Their VR environment was a city context, and participants navigated with hand-held controllers freely. In this two-minute task, they were provided an avatar and did active navigation in the environment. Lachlan and Krcmar (2011) investigated the influence of past game experience on spatial presence experience in an interactive video game and found that individuals with higher game experience had higher levels of spatial presence. Their game was a Xbox console game played with a joystick where users can interact with other game characters to collect information and clues. The researchers claimed that game experience does not predict perceptions of spatial presence alone, recommending an exploration combination of game experience with other factors. Larkin (2015) also found greater game skills associated with creating strong SSMs and higher levels of self-location and possible actions in a stereo 3D game. Weibel and Wissmath (2011) found a significant impact of immersive tendency and motivation to play the game on perceptions of spatial presence in games. In summary, previous studies showed that game experience, motivation to play, domain interest, and spatial ability have an impact on the spatial presence experience, and however there is a gap in the literature to explore these constructs in VR educational games. This study provides insight into that gap by exploring the influence of game experience, VR experience and content prior knowledge on users' development of spatial presence.

METHOD

Participants

The study included participants aged between 14 and 19 years (mean 16 years) from two urban high schools. A total of 56 students played the Cellverse game, completed pre and post assessments, and participated in interviews. Five students were first year honors biology students in School 1, 32 students were senior level biology students in School 1, 19 students were a part of AP biology class in School 2. Participants' VR experience and self-descriptions as game players are shown in Table 1.

Insert Table 1

The Cellverse Game

Cellverse is an immersive 3D VR game developed to help students learn cell biology. The goal of the game is to have players learn about the process of protein synthesis from DNA to RNA to amino acid chains by exploring a virtual cell. Players are told that the cell has one of five classes of cystic fibrosis, and their goal is to use an HMD and hand controllers to collect clues and determine the type of cystic fibrosis the cell has in order to choose the appropriate diagnosis for the cell. The game has a few different parts; in this study we focus on the part of the game where players learn about the process of translation of RNA into proteins (see Figure 1). As they are exploring the environment, players learn about the name and location of organelles and their relative sizes, and shapes (See Figure 2).

Students were introduced to the purpose of the game, headset, hand controllers and VR environment. Students played the game for a maximum of 25 minutes individually during class time. They received technical support with the HMD and hand controllers, but not content support or game direction from researchers while playing the game. All participants used the whole play time given; students who did not complete the game were asked to stop at the 25 minute mark. After they finished the game, students participated in a brief interview, and took an online questionnaire.

-Insert Figure 1 here-

-Insert Figure 2 here-

Instruments

MEC Spatial Presence Questionnaire

Vorderer et al. (2004) developed and adapted a set of questionnaires (MEC-SPQ) based on Wirth's Spatial Presence Model (Wirth et al., 2007; Wirth et al., 2003), and then tested the questionnaires with different types of media. Although Vorderer et al. (2004) developed both short and long versions of the scales for questionnaires, the long versions were used in the present study. Detailed information about the questionnaires are explained below:

Attention Allocation

This is an 8 item scale consisting of items how users direct their attention to certain parts of a given image or simulation (For instance: "I directed my attention to the [medium], "My attention was caught by the [medium]"). Vorderer et al. (2004) found the Cronbach alpha level of this scale to be .93, in the present study it was found to be .88.

Spatial Situation Model (SSM)

This is a 8 item scale consisting of items describing the process of how users created a mental model of the environment during the activity (For instance: "I was able to imagine the arrangement of the spaces presented in the [medium] very well", "I was able to make a good estimate of how far apart things were from each other"). Vorderer et al. (2004) found the Cronbach alpha level of the scale .90, in the present study it was found to be .88.

Spatial Presence: Self Location

The Spatial Presence score is the mean score of Self Location and Possible Actions. The Self-Location scale is an 8 item scale consisting of items to explore users' perception of being in the environment during the experience. (For instance: "I felt like I was actually there in the environment of the presentation", "I felt like the objects in the presentation surrounded me"). Vorderer et al. (2004) found the Cronbach alpha of this scale to be .93, in the present study it was found to be .94.

Spatial Presence: Possible Actions

This is an 8 item scale consisting of items about users' perception of being able to interact with the virtual environment (For instance: "I felt like I could jump into the action", "I felt like I could move around among the objects in the presentation”). Vorderer et al. (2004) found the Cronbach alpha level of this scale to be .88, in the present study it was found to be .80.

Domain Specific Interest

This is an 8 item scale consisting of items that explore how users are interested in the topic of the environment (For instance: “I am generally interested in the topic of the [medium]”, “The [medium] corresponded very well with what I normally prefer”). Vorderer et al. (2004) found the Cronbach alpha level of this scale to be .93, in the present study it was found to be .93.

Visual Spatial Imagery Ability

This is an 8 item scale consisting of items to learn users’ existing ability to construct a mental model that includes positional relationships between objects. This can include being able to visualize moving through an environment based on a map, or imagine how a three dimensional space would look from a two dimensional diagram (for instance: “When someone shows me a blueprint, I am able to imagine the space easily”, “When I read a text, I can usually easily imagine the arrangement of the objects described”). Vorderer et al. (2004) found the Cronbach alpha level to be .82, in the present study it was found to be .75.

Cell Prior Knowledge Survey

The prior knowledge survey included questions about knowledge of cellular organelles, size, quantity and location of organelles, and the translation process. Multiple choice questions were scored, then coded as 0 (incorrect) or 1 (correct).

Data Analysis

We used principal components analysis (PCA) to analyze the items of the MEC Spatial Presence Questionnaire. Assumptions were checked before analysis and Kaiser-Meyer-Olkin Measure Adequacy (KMO) found to be .67 (above .6) and Barlett’s Test of Sphericity value found to be .0 ($p<.05$). A correlation matrix showed some correlations of $r=.03$ or greater, which showed the data set is suitable for PCA (Pallant, 2007). Results revealed twelve factors (eigenvalues >1), explaining 80% of the variance. The items of questionnaires that did not empirically belong to the intended construct were removed (one item from visual spatial imagery and two items from SSM scale). Principal components analysis revealed six factors (eigenvalues >1), explaining 32%, 13%, 10%, 8%, 6%, 5% of the variance in the outcome of spatial presence respectively. This six component structure explained a total of 74% of the variance in spatial presence. An oblimin rotation was performed and the rotated solution resulted in similar structure. The six components structure was consistent with the previous studies on MEC spatial presence questionnaire (Wirth et al., 2007).

Standard multiple regression analysis was conducted by including variables step by step to learn how much variance in spatial presence can be explained. The data met all assumptions of multicollinearity, linearity, and homoscedasticity needed for multiple regression analysis (Pallant, 2007). According to Stevens (1996, p. 72), “for social science research, about 15 subjects per predictor are needed for a reliable equation (as cited in Pallant, 2007). In the present study, a maximum of four predictors were used in one equation, which requires 60 subjects. In the present study, we had 56 participants, which practically met the criteria.

RESULTS

Regression Analysis Results

All constructs (SSM, attention allocation, visual spatial imagery and domain interest) that exist in the second stage of Wirth’s model (Wirth et al., 2007) were introduced into the model one by one to understand how much variance in spatial presence can be explained by these constructs. Results of the model showed that correlations between independent variables were all below 0.70, then standard multiple regression analysis was performed. The results of correlation coefficients are presented below.

-Insert Table 2 here-

Phase 1

-Insert Table 3 here-

The first model included only SSM, and was statistically significant (F (1, 55) = 19.0, p<.05), meaning that SSM explained 25% of the variance in spatial presence. SSM made a significant contribution (beta=.50, p<.05) in this model. The second model included SSM and added the impact of attention allocation. The second model was also significant (F (2, 53) = 16.25, p<.05). SSM and attention allocation variables made significant contributions to the variance in spatial presence in model 2, increasing the total variance explained to .38 (38%). In this equation, the beta coefficient of .41for SSM indicates that SSM makes the largest contribution to explaining overall Spatial Presence. Attention allocation (Beta=0.37) made less of a contribution to Spatial Presence. Model 3 and Model 4 added the impact of domain interest (F (3,52)=10.93, p>.05) and visual spatial imagery F(4,51)=8.04; p>.05), but neither of these variables made significant contributions.

Phase 2

The results of the first phase show that attention allocation and SSM explain variance in Spatial Presence, but domain interest and visual spatial imagery ability did not. In phase 2, we examine how to explain the variance in attention allocation and SSM. In the first regression, we explore how much of the variance in attention allocation was explained by domain interest and visual spatial imagery. Correlation coefficients are presented below.

-Insert Table 4 here-

-Insert Table 5 here-

We ran a linear multiple regression to explore the impact of domain interest in the attention allocation variance. In this model, DI explained 25% of the variance in attention allocation, and was significant F (1, 54) = 8.66, p<.05. The second model added the impact of visual spatial imagery to Model 1, and was also significant (F (2, 53) = 6.80, p<.05). The total variance in attention allocation increased, demonstrating that up to 20% of the variance in attention allocation is explained by two factors: visual spatial imagery ability and domain interest. Domain interest (Beta=0.31, p<.05) explained more of the variance than visual spatial imagery (Beta=0.27, p<.05). Users' interest in the domain of the VR game and their visual spatial imagery ability have an impact on their attention allocation.

We ran linear regression analysis to test whether there was a relationship between SSM and visual spatial imagery. Although Wirth et al.'s model (2007) reveals a significant relationship between these variables, we could not find any significant relationship (F (1,54)=1.30, p>05).

Phase 3

In the last step, we ran a regression analysis to explain the variance in spatial presence by integrating VR experience, game experience, and cell prior knowledge. VR and game experience variables were converted into dummy variables in order to run the regression analysis. The model was not significant (F (6, 55)= 1.19, p>.05), suggesting that VR experience, game experience, and prior knowledge do not influence players' experiences of spatial presence during the game. The overall regression analysis results are depicted in the figure below.

-Insert Figure 3 here-

DISCUSSION

This study contributed to existing research by implementing Wirth et al.'s (2007) Spatial Presence Model to a VR educational game with the addition of prior content knowledge, VR experience, and game experience in order to understand how learners experience spatial presence in a VR learning environment.

According to Wirth et al.'s (2007) model, users form a perception of spatial presence in two ways: users form a mental model of the environment by engaging in the VR environment, and users develop a sense of the environment from an ego-centered perspective. In the present study, we focused on how users build a mental model of the spatial environment, and we tested variables to determine whether the variables had an impact on this process. Results suggest that SSM explained 25% of the variance in spatial presence, which is consistent with previous results (Wirth et al., 2007, Wirth et al., 2003, Hofer et al., 2012). Attention allocation and SSM both explained 38% of the variance in spatial presence. Attention allocation directly influenced the formation of spatial presence in our study, which aligns with results from other studies (Hartmann et al., 2016; Sacau et al., 2005). According to Wirth et al.'s (2007) Model, attention allocation is a prerequisite for forming SSM; in this study, our results did not confirm that attention allocation is a predictor of SSM. Moreover, there was no association between visual spatial imagery and SSM, which is inconsistent with previous studies (Wirth et al., 2007; Coxon et al., 2016, Hartmann et al., 2016). One of the differences between previous studies and our study is the virtual environment. This study used a VR learning environment where players were immersed in the VR environment through a HMD headset and had hand controllers to interact with the environment. For instance, in the study of Coxon et al. (2016), the VR environment was a city context, and participants navigated with hand-held controllers freely. In this two-minute task, they were provided an avatar and navigated in the environment. However, participants did not complete multiple and challenging tasks and did not interact with the environment. The level of immersion and interaction in VR might enable users to build a spatial model of the environment even without paying attention to the environment or drawing from their visual spatial imagery abilities. This finding is similar to that of Sacau et al. (2007), who could not find any association between visuo-spatial imagery and spatial presence in their investigation of the role of visual imagery ability on spatial presence in different environments (linear text, hypertext, film, and virtual environment). They attributed this discrepancy to questionnaires that were unable to detect differences in visuo-spatial imagery ability.

Ling et al. (2013) used a helmet setup similar to an HMD in their study of the association between spatial presence and spatial intelligence (mental rotation test) in three different virtual environments, however they could not find a significant relationship between spatial presence and spatial intelligence. They claimed that spatial intelligence might be crucial in complicated 3-D environments when spatial activities and more interactions are performed. They used a single room and a speaking environment as a virtual environment in which interaction level might be quiet low. The present study has two main differences. First, we used a complicated 3D VR environment where students navigate, search for clues, and interact with the environment through hand controllers. In the 25-minute game, players needed to accomplish tasks, navigate through organelles, search for clues, and establish a mental model of the environment. The design and layout of the environment were abstract and densely packed with organelles, similar to an actual human cell, thus it was not easy to navigate or find target organelles and comprehend spatial surroundings in such a complex learning environment. VR educational games are quite different than computer 3D games; immersion in the game through the head mounted display (HMD) provides a strong feeling of presence (being there) and increases the level of interactivity with the game (users can move in their actual environment in response to the game).

Coxon et al. (2016), studied the association between different spatial abilities including visio-spatial imagery, mental rotation, and topographical memory among users using an HMD. They only found a significant relationship between visio-spatial imagery and spatial presence, but no relationship between spatial presence and other spatial abilities. Wirth et al.'s (2007) model claims that visio-spatial imagery is one of the predictors of the first step of experiencing spatial presence - developing the spatial mental model of the environment. Even though we could not find evidence of this association, we found out that visual spatial imagery is a positive predictor of attention allocation. Individuals with higher visio-spatial skills reported higher attention allocation. According to Wirth et al.'s (2007) model, individuals who have an interest in the content are more likely to draw their attention to the environment, which would result in a stronger perception of spatial presence. In addition to individual interest in the topic, attention can also be triggered and sustained through media-related factors. The finding that domain interest is one of the positive predictors of attention allocation is an interesting outcome of this study. We believe this result may be due to the complexity of our VR environment; students with high spatial ability might be able to direct their attention to the stimulus provided in the complicated VR environment. Moreover, during the game, players need to perform activities such as navigating and searching, which also require higher spatial abilities.

We found that game experience, VR experience, and prior content knowledge were not significant predictors of spatial presence. Interest in the topic had a significant impact on attention allocation and spatial presence as well, but prior knowledge did not have an impact on the sense of spatial presence. Existing research suggests that higher levels of perception of spatial presence might result in higher performances on spatial knowledge assessments (Parong et al., 2020); but that more prior knowledge about the topic did not have an impact on spatial presence. We assessed students' content prior knowledge in cell biology. However, this VR game provides representation of a human cell in a complex and realistic way. High school students mostly encounter cells via text books that provide 2-D representations of cells with simple designs (Flores et al., 2003) Thus, students may not have been able to construct a spatial understanding of this new and abstract environment.

Relationships between game experience and VR experience and spatial presence have conflicting results in the literature. Previous studies using interactive video games in desktop systems found that individuals with higher game experience or game competence had higher levels of spatial presence (Lachlan & Krcmar, 2011; Larkin, 2015). The participants in these studies were over 18 years old. This study included participants aged between 14 and 19 years (mean 16 years). Ling et al. (2012) also could not find a significant effect of computer experience and game playing experience on spatial presence. The age range of their sample was between 18 and 65 years, with a mean age of 28. They used different forms of virtual environments, and one of them was a high fidelity immersive VR environment. Our study used an immersive VR game played via HMD headsets. The results of this study suggest that there is not an association between VR and game experience and spatial presence. One explanation for this could be that the immersion possible with the HMD and VR experiences are able to gather and hold users' attention more effectively than other virtual experiences. Media-related factors such as the reality of the environment and the ability to interact with the environment with hand controllers might also play a crucial role in triggering participants' attention and increasing experience of spatial presence. Moreover, there is a gap in the literature exploring the effect of VR experience on spatial presence. VR is still fairly new technology, and it is not easy to find participants in different ages with different levels of VR experience. Future studies can explore the effect of age and its association with VR and game experience in establishing a sense of spatial presence. All research in VR, including this study, is impacted by the rapid development of VR technology. The rapid pace of development in VR technology will impact future studies, and future research will be influenced by the changing hardware and software for VR.

As with all studies, this study has limitations. One limitation is small sample size. This was due in part that a researcher had to facilitate the game rather than the game being entirely playable by the participants, as not all of the game functions were complete at the time of the study. The study was conducted in school classrooms, and all technology had to be transported and set up every day. Conducting experiments with VR technology is not an easy process and takes a lot of time. The questionnaires are self-reported, and responses could be affected by social desirability bias. In future studies, we would add more personal traits such as mental rotation ability, confidence level, and attitude, increase the sample size, and add more types of data, such as performance tasks.

CONCLUSION

In this study, we have extended Wirth et al. (2007)'s model of spatial presence by including background knowledge and prior experience specific to VR and educational games to better understand users' process of forming spatial presence. We found that spatial presence is a result of users building a spatial model of the environment (SSM) and allocating attention to critical features within the environment. Attention allocation is related to both users' interest in the domain and their existing visual spatial imagery ability. However, prior knowledge and experience do not completely determine users' formation of spatial presence, as we found no association between users' game experience, VR experience, and prior knowledge about the topic of the game and their formation of spatial presence.

Based on our results, users' perceptions of spatial presence are a result of how they allocate their attention and how they build the spatial model of the environment. Since attention allocation is important, it's useful to know how to direct users' attention in a virtual environment. Users' attention can be triggered by media-related features in the environment (Hartmann et al., 2015), thus designers should continually revisit their learning objectives as they create the environment and establish how the user interacts with the environment. Domain-interest and visual spatial imagery ability also play crucial roles for how learners direct their attention to the stimuli in the environment, thus designers should find ways to spark interest in the experience, and support users' visual spatial imagery ability by pre-training or segmenting (Mayer & Moreno, 2003). Findings from this study also suggest that designers may not have to consider users' prior VR and game experience, as they did not have an association with spatial presence.

We also found clues about who might benefit from these kinds of immersive VR learning environments. Prior experience in VR technology, video games and prior knowledge of the content in the game are individual differences that will not necessarily have an impact on spatial presence experiences. On the other hand, interest in the topic and spatial visual imagery ability are factors that might affect how learners draw their attention to the stimulus; this could explain why learners experience different levels of spatial presence even though they are exposed to the same VR environment. In addition to media-related factors such as enhancing visual quality and using an HMD to increase immersion, it is important to create and support interest in the content in the virtual experience. Moreover, spatial abilities might impact how users experience spatial presence. Creating complex spatial environments that require multiple spatial tasks to perform such as navigating, way-finding, and recognizing and locating objects are likely to be more challenging for users with low spatial abilities than with users with higher spatial abilities. However, VR and spatial ability are complementary; VR can be used to measure spatial ability and to enhance it (Uz Bilgin, Anteneh & Thompson, 2020). Future studies could explore how users' existing spatial ability can be improved through VR environments. Additionally, future research can explore different ways of measuring spatial presence development beyond self-report. As VR technology becomes more widespread, understanding the process of how users' develop spatial presence and also how designers can support users' development is an important contribution to the field.

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Tables

Table 1. Participants' Game and VR Experiences (frequency (f) and percentage (%))

Game Player, f (%)		**VR Experience, f (%)**	
Definitely yes	25 (45%)	Yes- many times	9 (16%)
Probably yes	11 (20%)	Yes, only once or twice	22 (39%)
Might or might not	10 (18%)	No	25 (45%)
Probably not	6 (11%)		
Definitely not	4 (7%)		

Table 2. Correlation between Spatial Presence and independent variables

	1 (SP)	2 (SSM)	3 (AA)	4 (VS)	5 (DI)
1. Spatial Presence (SP)	-	.50*	.47*	.19	.31*
2. Spatial Situation Model (SSM)		-	.25*	.15	.23*
3. Attention Allocation (AA)			-	.33*	.37*
4. Visual Spatial Imagery (VSI)				-	.22
5. Domain Interest (DI)					-

**significant at the .05 level*

Table 3. Multiple Regression Results of Phase 1

	F	*p*	R^2	*SE*	*β*
M1 (SSM)	18.19	0.00	.25	.10	.50*
M2 (M1+Attention Allocation	16.25	0.00	.38	.09 .09	SSM (.41*) AA (.37*)
M3 (M2+Domain Interest)	10.93	0.00	.38	.09 .10	SSM (.40*) AA (.34*) DI (.09)
M4 (M3+Visual Spatial Imagery)	8.04	0.00	.38	.10 .10 .08 .11	SSM (.40*) AA (.34*) DI (.09) VSI (.00)

**Significant at the .05 level*

Table 4. Correlation between attention allocation and independent variables

	1 (AA)	2 (DI)	3 (VSI)
1. Attention Allocation (AA)	-	.37*	.33*
2. Domain Interest (DI)		-	.22*
3. Visual Spatial Imagery (VSI)			-

**Significant at the .05 level*

Table 5. Multiple Regression Results of Phase 2

	F	*p*	R^2	*SE*	*β*
M1 (DI)	8.66	0.00	.14	.10	.37*
M2 (M1+VSI)	6.80	0.00	.20	.10 .14	DI (.31*) VSI (.26*)

**Significant at the .05 level*

Figures

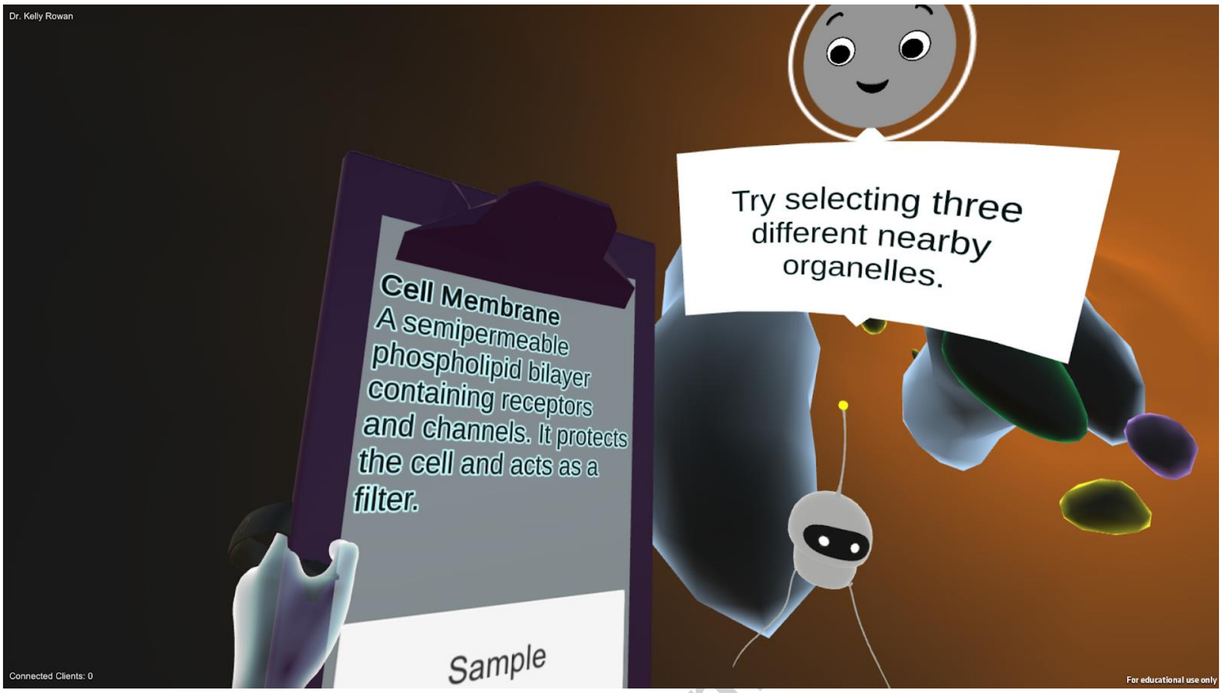

Fig. 1. Translation process in the Cellverse Game

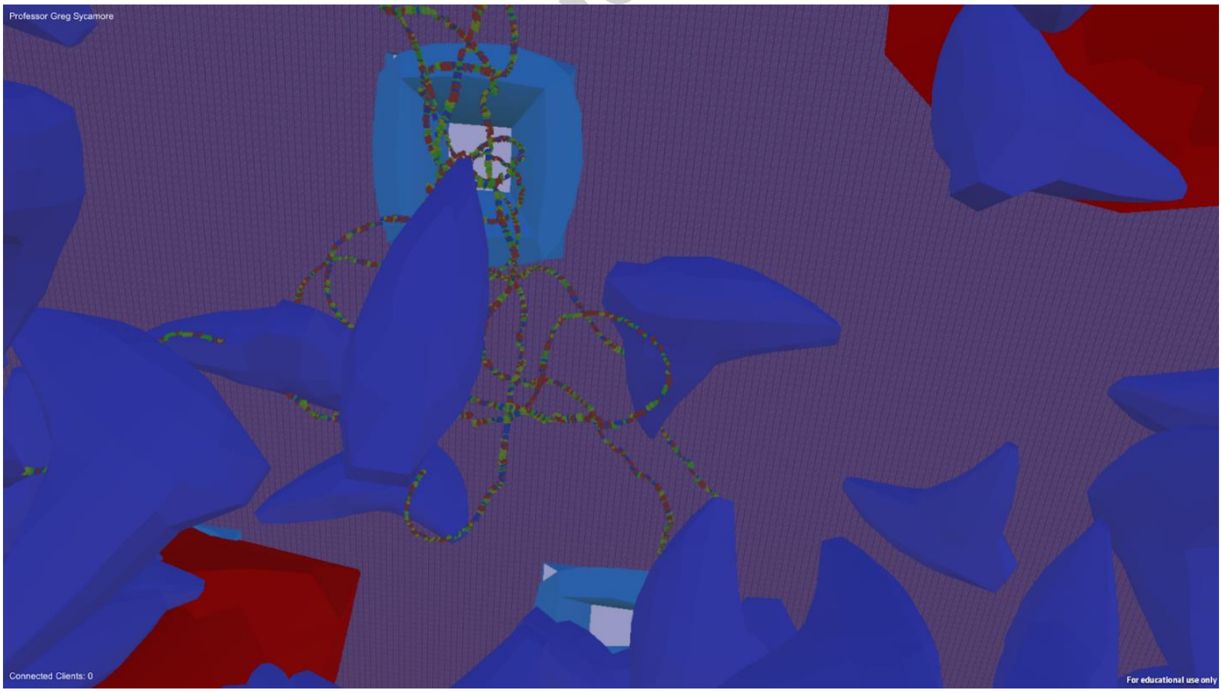

Fig. 2. Organelles in the Cellverse Game

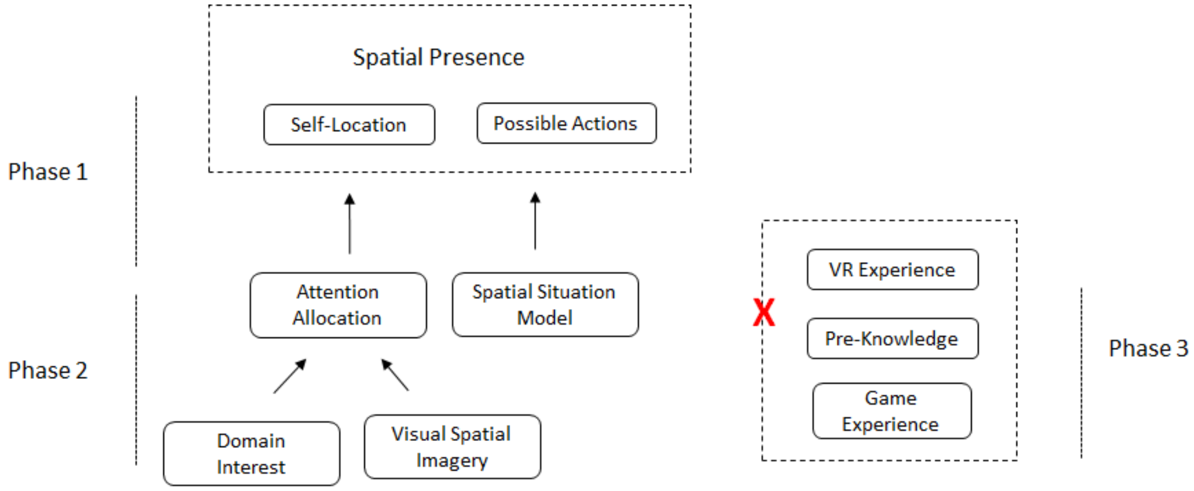

Fig. 3. Depict of Regression Analysis Results