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Research-in-Progress

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Abstract

Virtual reality has received attention as an environment for learning, yet little is known about the effectiveness of bringing the immersive visualization systems into the university classrooms. Building upon prior literature on immersive technology and the theory of affordance, we develop a model investigating how the features afforded by an immersive visualization system escalate users' engagement, which in turn increases their learning outcomes. We will test the model with undergraduate students who have experienced with an immersive visualization system in the classroom setting. We believe that our work will enrich the existing literature on virtual reality in education and provide insight into the design of immersive representations and the structure of immersive learning paradigm.

Keywords: Immersive visualization systems, affordance, aesthetic experience, system satisfaction, learning outcomes

Introduction

Technology allows institutions to present high-quality virtual environment using Immersive Visualization Systems (IVSs) at a relatively low cost. An IVS creates a complete sense of presence in a virtual world enabled by high-resolution, stereoscopic projection and two-dimensional (2D)/ three-dimensional (3D) computer graphics or animation supplemented with realistic 3D sound effects. IVSs have been widely applied in various areas, particularly education. Since the next generation of students no longer is satisfied with the traditional chalk-and-talk pedagogical approach, an IVS break the limitations of the classroom setting by facilitating a strong and vivid visual understanding of a subject matter. Besides, its ability to enable simultaneous immersion of multiple users in the same artificial computer-generated environment with which the users can interact makes it an ideal tools for collaborative learning by simulating and visualizing various venues or scenarios such as volcano (Melbourne Museum, 2010), wildfire (Hoang et al., 2010), underground mining (Stothard and Laurence, 2014), archaeological site (Bruno et al., 2010), and sports training (Ruffaldi et al., 2011).

Collaborative learning describes the circumstance in which at least two individuals try to learn something together (Dillenbourg, 1999). Prior studies reveal that collaborative learning in virtual environments results in a positive educational effect in higher education (e.g., Cheney and Sanders, 2011; Goel et al., 2013; Huang et al., 2010; Park and Park, 2016; Quintana and Fernández, 2015) so that there is an urge for integrating immersive modes of learning into collaborative learning for the next generation learners in higher education (e.g., Cheney and Sanders, 2011; Huang et al., 2010).

The advantages of using IVSs for education mainly come from the visualization, realism and interactivity features of the virtual environments (Bruno et al., 2010), features that are difficult to be provided, if not missing, in a conventional classroom setting. An IVS provides a stereoscopic, graphical presentation of complex or abstract concepts (Stothard and Laurence, 2014) such as algebraic notions or rich information in a way which is impossible in desktop displays (Hoang et al., 2010). Moreover, showing realistic scenarios or venues may be costly or difficult to simulate or visit (Hoang et al., 2010; Stothard and Laurence, 2014). IVS helps break the physical and temporal limitations (Bruno et al., 2010) and provide "on-site" opportunities in which learners can train their instant reactions to incidents or sharpen their skills (Ruffaldi et al., 2011) through repeated training in a safe environment without the possibility of causing harms to any parties or the venue. Furthermore, the graphics or animations shown by the system can be changed flexibly and instantaneously according to user inputs and training needs (Ruffaldi et al., 2011), making the interaction process with the system and with peers interesting and appealing (Bruno et al., 2010).

Despite the benefits of IVSs for education, the investment of developing an IVS application for collaborative learning cannot be justified if its educational effect is not significant. In this regard, little research has empirically unveiled the cognitive-psychological mechanism of how the essence of IVSs for collaborative learning improves users' learning outcomes by affecting their perceptions of both the learning experience and the system. There is a need to understand how IVSs advance classroom teaching. This study aims at filling this research gap by answer the following questions:

(1) What are the affordances that capture the essence of IVSs?

(2) How do they influence learning outcomes of IVS applications for collaborative learning?

Building upon the Interaction-Immersion-Imagination framework of virtual reality (Burdea and Coiffet, 2003), and the theory of affordance, we propose a model which is anticipated to improve our understanding of the cognitive and psychological perceptions of users toward using IVSs for education purpose. The research model states that the three affordances of an IVS proposed are positively related to the meaningful engagement of users with the IVS, known as aesthetic experience, which in turn determines both their satisfaction level with the system and their learning outcomes. We also argue that users' system satisfaction with IVS affects their learning outcomes. We expect that the results of this study can provide insights into research and practice. First, this study extends the framework of VR by conceptualizing and operationalizing the affordances of IVSs for collaborative learning which are not available in the previous information systems literature. Second, the findings of this study will expose which and how affordances of IVSs for collaborative learning work with user engagement in determining their satisfaction level with the system as well as their learning outcomes, thus providing insights for designing and developing effective IVSs for learning.

Theoretical Background

The Interaction-Immersion-Imagination framework of virtual reality and the theory of affordance serve as the theoretical foundation of this study.

The Interaction-Immersion-Imagination Framework

Virtual reality (VR) is a coherent triad of "Interaction-Immersion-Imagination" (three I's of VR) (Burdea and Coiffet, 2003), which covers the functional, perceptual and affective characteristics of VR. Interrelated to each other, interaction, immersion, and imagination are the consequences of a user immersing in a virtual environment. They are the features that enable a VR application to transport people into an alternate virtual space in a way that no other technology can do because pictorial communication is usually more efficient and effective than textual ones. Human beings tend to comprehend images faster than lines of text.

Interaction, a fundamental feature of VR, is the ability of the system to sensitively detect and instantaneously respond to users' inputs (such as gestures and voice commands) by changing the virtual environment accordingly (Burdea and Coiffet, 2003). *Interaction* refers to "the extent to which users can participate in modifying the form and content of a mediated environment in real time" (Steuer, 1992, p. 84). An IVS uses visual, audio, and other sensational cues to create an artificial reality with which users interact. User interaction with an IVS can vary from simply looking around to interactively modifying the virtual environment by giving instructions through position tracking systems or input devices. *Immersion* refers to the mental state of total absorption in the virtual environment enabled by, in addition to a high degree of real-time interaction, the rich information perceived through multiple sensory channels (Burdea and Coiffet, 2003). Shin (2017) argued that users of a VR system play an active role in the formation of immersion through their conscious interaction with the system. Immersion is affected not only by the audiovisual cues provided by a VR system but the traits and social contexts of individual users. *Imagination* refers to the capacity to creatively picture in one's mind something nonexistent (Burdea and Coiffet, 2003). Since VR is experience-driven rather than information-driven, imagination plays a role in making a virtual environment an attractive and successful one, no matter it is a re-presentation of the reality or a creation of an imaginary territory. Hence, the integrated triad of interaction, immersion, and imagination are embedded in VR.

Theory of Affordance

The concept of affordance in the theory of affordances refers to "a specific combination of the properties of its substance and its surfaces with reference to an animal" (Gibson, 1977, p.67). An affordance can be interpreted as an opportunity provided by the environment of an animal. It is determined by the relation between a physical property of the environment and the characteristics of the animal. For example, the surface of a river affords walking for water bugs but not for human beings. Norman (1990, p.9) defined affordances similarly as the properties of an item that allows it to function. Affordances of an item suggest how it could be used, e.g., knobs are for turning, handles are for holding, etc. An ideal design should contain affordances that serve as direct, strong clues of its proper operation.

The affordance perspective captures the unique life-like characteristics of VR which are not available in older technologies (Goel et al., 2013), and can emphasize the impact on learning afforded by VR rather than VR itself (Dalgarno and Lee, 2010). The concept of affordance has been introduced to the studies of learning in higher education such as desktop virtual reality learning environment. For example, Goel et al. (2013) argued the unique characteristics of virtual worlds are their social and context facilitation and found that both of them are positively related to perceived learning, learning satisfaction and task participation via cognitive absorption. Shin (2017) proposed that two affective affordances of the virtual reality learning environment (immersion and presence) affect two educational affordances (empathy and embodiment) via comfortability affordance (usability).

Interaction, Immersion, and Imagination Affordances

The theory of affordance can explain not only what an artifact provides to the actor but also the opportunities exist when the actor meets the artifact. The theory is employed in this study to identify the essence of IVSs because, as Dalgarno and Lee (2010) suggested, it emphasizes how IVSs afford the experience in using them instead of what features they provide. The theoretical lens of affordance thus highlights the relationship between the actor (i.e., users) and the object in question (i.e., IVSs for collaborative learning in higher education), in addition to the characteristics inherent to the object.

Based on the Interaction-Immersion-Imagination framework (Burdea and Coiffet 2003), we conceptualize interaction affordance, immersion affordance, and imagination affordance as the affordances of IVSs. We provide a brief description of each affordance, as well as the anchoring literature and example features in Table 1.

Table 1. Immersive Visualization Systems Affordances

Affordance	Definitions in the VR learning environment	Related affordances in prior literature	Example features
Interaction	Users perceive system responsiveness to their inputs	- Autonomy (Zeltzer, 1992) - Context/ Social facilitation (Goel et al., 2013) - Interactive simulation (Radu, 2014) - Learner interaction (Dalgarno and Lee 2010) - Vividness (Naimark, 1990)	- Control of environmental attributes and behavior - Construction of objects and scripting of object behaviors - Detecting user inputs (e.g., gesture, position) - Embodied actions including view control, navigation and object manipulation - Embodied verbal and non-verbal communication - Simultaneously responding to user inputs by changing the visual or auditory display
Immersion	Users feel that they are part of the virtual environment. It is the users' affective affordance experienced over time	- Cognitive absorption - Flow (Csikszentmihalyi, 1990) - Physical (or sensory) immersion (Sherman and Craig 2003) - Presence affordance (Shin, 2017) - Mental immersion (Shin, 2017) - Temporal contiguity effect (Mayer and Moreno, 2003) - Representational fidelity (Dalgarno and Lee 2010)	- Absorption, concentration, and engrossment - Multiple representations - Role-projection - The sense of embodiment - Rich graphics, smooth temporal changes, and consistent object behavior - Stereoscopy
Imagination	Users perceive that they are in an incredible simulation of a real surrounding or a fantasy territory	- Authentic 3D experiences (Gamage et al., 2011) - Artificial 3D experiences (Gamage et al., 2011) - Directed attention (Radu, 2014) - Realness (Naimark, 1990) - Spatial contiguity effect (Mayer and Moreno, 2003)	- Kinaesthetic and tactile force feedback - Media richness - Realistic display of the environment - Smooth display of view changes and object motion - Spatial audio - The consistency of object behavior - User representation - Visualization of a scenario/ a concept

Research Model and Hypotheses Development

In this study, we propose that affordances of an IVS affect users' aesthetic experience from using the system, which in turn influences their satisfaction with the system as well as their learning outcomes. Figure 1 depicts our research model and hypotheses.

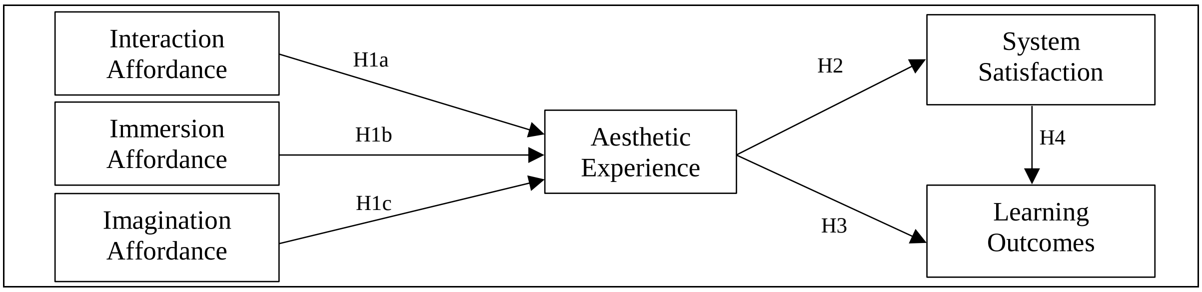

Figure 1. Research Model

Aesthetic Experience

Aesthetic experience refers to users' awareness of how to proceed and of what counts as the fulfillment of the purposes and objectives being pursued within a system (Suh et al. 2017). It is a meaningful user engagement (Dewey 1934) that is the awareness of the relationship between the task environment and self. Prior studies found that employees' aesthetic experience from using a gamified information system affects their intention to continuously use the system at their free will for knowledge sharing and collaboration (Suh et al., 2017). In other words, aesthetic experience can reflect users' state of mind in which they understand the meaning of their interactions with the system (e.g., IVS).

Interaction, Immersion, and Imagination Affordances and Aesthetic Experience

Affordances induced by IVS allow users to have meaningful and deep interactions with the IS (Goel et al. 2013). In this study, we adopt the three IVS affordances (i.e., interaction, immersive, and imagination) suggested by Dalgarno and Lee (2010) to investigate how the IVS affordances engage students with the virtual learning activities.

Interaction affordance, which users' perception of system responsiveness to their input, is a desirable feature of IVSs. If users find the interaction with an IVS appropriate, they will perceive the experience a cheerful one and will continue to stay in the immersive learning environment. It is anticipated that the longer they stay in the immersive learning environment or, the more pleasing the experience is, the easier they find their learning experience a meaningful one. The better an IVS affords interaction, the easier the aesthetic experience emerges.

Immersion, which refers to users' engagement in the virtual world and, is a goal affordance (Scarantino, 2003) of IVSs. Immersion makes users temporarily forget the real world and fully concentrate on the immersive learning environment. It is expected that the more attention they pay to the immersive virtual world, and the more meaningfulness they perceive from the learning experience. The better an IVS affords immersion, the deeper the meaning, i.e., aesthetic experience, and users' absorption.

Imagination, which refers to the ability to envision something inexistent, is the ingredient that makes immersing in an artificial environment amusing. It is believed that the more boundless the imagination is, the greater the chance he finds meaningfulness from the learning experience. The better an IVS affords imagination, the easier the aesthetic experience a user discovers. Hence, we hypothesize as follows:

H1: Interaction affordance (H1a), Immersion affordance (H1b), and Imagination affordance (H1c) of an IVS for collaborative learning positively affects users' aesthetic experience from using it.

System Satisfaction

In this study, users' system satisfaction level with an IVS for collaborative learning is defined as their overall affective and cognitive evaluation of the pleasurable level of fulfillment experienced with IVS. Prior studies of IT end-user satisfaction have found that end-user information satisfaction is strongly affected by their perceived benefits (Mahmood et al. 2000). Since aesthetic experience from using an IVS for collaborative learning is a positive consequence of using the system, it is considered as part of the perceived benefits of using the system (e.g., improving their understanding of the course content in a meaningful way). It is therefore assumed that the finding from Mahmood et al. (2000) applies in the current context of using IVSs for education purpose. Hwang and Thorn (1999) also found in their meta-analysis of 25 prior studies that user engagement had a positive correlation with users' system satisfaction. It is logical to assume that their finding also applies in the context IVS and that the aesthetic experience from using an IVS for education purpose positively affects users' system satisfaction toward the IVS. Hence, we hypothesize:

H2: Aesthetic experience from using an IVS for collaborative learning positively affects users' system satisfaction level.

Learning Outcomes

In this study, we define learning outcomes as users' academic performance because it is a direct and relatively objective indicator for evaluating the effect of employing IVS for collaborative learning.

Aesthetic experience exists when an event is different from others to a person in the sense that it is beneficial to him in an intangible way. Lee et al. (2010) found in their study on how desktop virtual reality enhances learning outcomes found that cognitive benefits (including "better memorization, understanding, application and overall view of the lesson learned") are positively related to learning outcomes. Their finding suggests that aesthetic experience from using an IVS for collaborative learning may be positively related to learning outcomes in general and academic performance in particular, given the similarities between IVS and desktop VR systems. Hence, we hypothesize:

H3: Aesthetic experience from using an IVS for collaborative learning positively affects users' learning outcomes.

Users' satisfaction with technology has a positive effect on learning performance (Lin, 2012). It implies that working within a satisfying interface or system affords users a sense of interactivity and competence to engage more in the processing learning activities (Sung and Mayer 2012), which in turn increase their learning outcomes. In this context, the interaction, immersive and imagination features of IVS make users feel more satisfied with the display and interaction generated by the system and therefore become more motivated to work hard to learn and increased their confidence of the learning tasks. In short, users' learning outcome is highly associated with how well they are satisfied with the use of IVS in their learning processes. Therefore, we hypothesize that:

H4: System satisfaction level on an IVS for collaborative learning positively affects users' learning outcomes.

Research Method

We will test the proposed research model with college students by collaborating with universities which have applied the IVSs in their educational curricula. All respondents will be the users of IVSs that are designed for facilitating collaborative learning.

Measures

This study has six constructs: interaction affordance, immersion affordance, imagination affordance, aesthetic experience, system satisfaction, and learning outcomes. The former three are conceptualized in this study. An instrument for measuring them cannot be found in the information systems literature. There is a need to develop a scale for interaction, immersion, and imagination affordances respectively. We followed Churchill's (1979) robust paradigm to develop and validate the scale. The instrument development paradigm consists of three major phases: (1) item generation; (2) instrument development; and (3) instrument testing.

Item generation: We followed a two-step procedure to create an initial pool of items (Belk 2014). We first collected relevant items from the existing literature, and then generated new items based on the definition of the constructs fitting the context of this study. ***Instrument development:*** The card sorting exercises were conducted to ensure the content validity of the initial set of items. The items were evaluated by a panel of experts. The panel experts were asked to carefully read each item and classify it into the corresponding construct and provide qualitative feedbacks toward the items. ***Instrument testing:*** An online questionnaire was distributed to thirty respondents for review and refinement. Cronbach's alpha was used for assessing scale validity and reliability. The values of all the items were greater than 0.70 to meet the conventional standards of internal consistency (Hair et al., 2009). The 11-item measure for the affordance constructs (four items from interaction affordance, five items from immersion affordance, and two items from imagination affordance) was produced.

Other measures will be adapted from various sources with modifications to fit the specific context of the current study. The aesthetic experience scale will be a modified version of the one from Suh et al. (2017). System satisfaction will be assessed by adapting items from McKinney et al. (2002) and Wixom and Todd (2005). The learning outcomes will adopt performance-based assessment criteria.

Data Collection Plan

In the main study, a survey will be conducted to test the proposed research model. The survey will be administered to approximately 100 university students. They will be invited to fill out a self-report paper-based questionnaire after they have experienced a session of collaborative learning using the IVS as required by one of the courses they enrolled in. The questionnaire will consist of three parts: (1) perceptions of the students, (2) open-ended questions asking their views on the system and (3) demographic information of the respondents including gender, age, prior experience in IVSs, course discipline, level of course, students learning motivation and performance prior to the class as the control variables. Each question in part (1) is rated on a 7-point Likert scale.

The IVS adopted for this study is a 360-degree stereoscopic projection environment. It supports a wide range of contemporary digital image-processing techniques including 2D or 3D animation, 2D or 3D video, panoramic photography, videography, surround-sound, and data visualization. These cognitively rich resources are integrated into different types of course-driven scenarios to present high-impact pedagogy for the arts and sciences. The IVS also employs mixed, augmented or enhanced reality to enable delivering even more effective immersive teaching and learning. The virtual environment will be designed to capture the live experience at 1:1 scale. Students will experience the virtual learning environment using this IVS.

Expected Contributions

The study develops a theoretical model that explains the impact of affordances of IVS on learning outcomes through users' aesthetic experience from using the IVS for collaborative learning and their system satisfaction. The expected contributions of this study are three-fold. First, this study extends the framework of VR by conceptualizing and operationalizing the affordances of IVSs which are not yet available in the IS literature. The new instrument will be useful for future studies in this research stream. In this way, we believe that this study will draw scholarly attention to using IVS as a technology-assisted education application. Second, the study will disclose details of how the essence of an IVS engages learners into the immersion experience. Specifically, the findings will indicate the magnitude of the impact of each of the affordances of IVSs on users' meaningful engagement, known as an aesthetic experience, which in turn affects their system satisfaction and learning outcomes. The findings will help to unveil the relationships between these constructs and increase our understanding of the role played by aesthetic experience. Third, practitioners will also benefit from the empirical study. The results of this study are anticipated to provide insights into the design and development of IVSs. For example, if interaction affordance has the strongest significant positive influence on aesthetic experience among the affordances of IVSs, then the direction of future system design should focus on enhancing the interactivity of the IVSs for education purpose. Moreover, instructors may adjust their pedagogical approach in a classroom setting according to the findings. A better understanding of the learning outcomes from using IVS will help organizations and institutions to make better investment decisions regarding the introduction of IVSs for learning or training purposes.

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