A Systematic Literature Review on the Intersection of Experiential and Multimedia Learning with Virtual Reality and its Implications

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Abstract

This literature review examines the current literature and research surrounding the foundations and applications of experiential and multimedia learning in virtual reality environments. Eleven insightful research papers are discussed, detailing the efforts and results of multimedia learning and experiential learning in virtual reality independently, not combined. The literature, and consequently the literature review, heavily pulls from Kolb's Experiential Learning model and Mayer's Cognitive Theory of Multimedia Learning. We find a general trend suggesting the efficacy of creating experiential learning-based lessons and the efficacy of multimedia learning formats. However, based on the literature, combining these two theories and techniques may result in higher student engagement and content retention. This literature review also explores the thresholds for sensory stimuli fidelities necessary to create meaningful, effective, immersive virtual reality content. However, further research will be required to measure attention, retention, and information recall in different virtual reality and multimedia lesson formats, as well as engagement and positive emotions associated with learning.

1 Introduction

Over a (college) semester, the team compiled a literature review on current research surrounding the effectiveness of using virtual reality technologies to allow for accessible experiential learning. Experiential Learning can be defined as interactive learning by doing; however, the specifics of the processes of this method will be later discussed in this paper. The team began by utilizing education theorist Richard Kolb's definition of the experiential learning model to compile findings on the method's effectiveness. Next, education theorist Richard Mayer and his research into multimedia learning styles with virtual reality as a supplement was incorporated into the literature review. Virtual Reality technology is the latest that employs a simulated experience in 3D near-eye displays via a head-mounted display (hardware). We aimed to see if combining these two learning styles via VR could create a synergy for the learner. Here VR is defined as "a high-end (complex) user interface that involves real-time simulation and interaction through multiple sensorial channels (visual and auditory stimuli)" (Burdea & Coiffet, 1994). As researchers, current Rutgers students, and founders of a VR EdTech startup, SageTech, the team seeks to understand if the technology is worth integrating into education as a supplement to multimedia learning and as an experiential learning method. In the exploration process, it was found that there is little research on VR in the educational space. As VR technology rapidly advances, including adaptive learning systems, gamification, and cloud systems, there is a need for scientific exploration into the effect alternative learning methods will have on learners. Educators, administrators, parents, and students must understand the integration and outcomes of VR to make a holistic decision on learning style preferences. Following Kolb's experiential learning model and Mayer's multimedia learning theory, a literature review of the implementations and implications of mixed reality in education was conducted. For this publication, significant components of the research were highlighted from the more extensive literature review on the subject.

2 KOLB'S MODEL OF EXPERIENTIAL LEARNING

Experiential learning is the process of learning by doing, first popularized by American education philosopher John Dewey in 1939 with his theory of education. Dewey emphasized student engagement and progressive education, claiming that educators must stimulate learning via experience.

In 1984, American psychologist, professor, and educational theorist David A. Kolb expanded Dewey's findings in his experiential learning theory. Cited in the Journal of Experiential Education, Kolb's model functions as both a cycle of the learning process and highlights four adaptive learning modes (Schenck & Cruickshank, 2015). This four-step cyclical process includes the *concrete experience* (feeling), *reflective observation* (watching), *abstract conceptualization* (thinking), and *active experimentation* (doing).

The concrete experience is a new experience or reinterpretation of an existing one requiring five themes: 1. The learner is an active participant, referring to the idea that learners are involved and participating in the learning process, such as interacting with a chemistry lab. 2. Knowledge is situated in a place and time, where learning is dynamic as opposed to static. It is influenced by the social, physical, cultural, and environmental factors in which it takes place, a crucial key in learning about historical and social movements. 3. Learners are exposed to a novel experience that involves risk, where "novel" constitutes as new or challenging event leading to opportunity for growth, like team projects. 4. Learning demands inquiry into specific real-world problems. Lastly, 5. Critical reflection acts as a mediator of meaningful learning, where thoughtful analyzation allows the learner to reflect, such as a paper outlining surprises and lessons understood. Second, reflective observation entails the learner reflecting on past experiences and considering their existing or new knowledge to identify gaps in understanding. Third, abstract conceptualization grabs the observations made in the previous stage to create a theoretical approach. Fourth, learners can test their theories and apply what they have learned to the world around them through active experimentation (1).

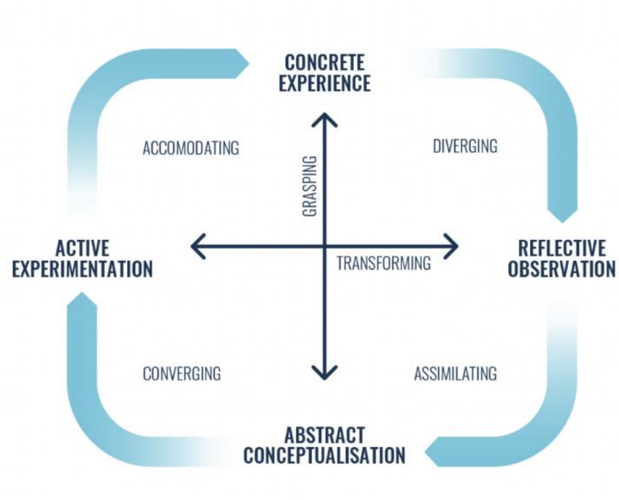

FIGURE 1: *Kolb's model of experiential learning*

Kolb's model is followed by four learning types, *accommodating, diverging, converging,* and *assimilating*. Accommodating can best be described as learning hands-on and self-reliance on intuition. Diverging applies to learners who prefer to watch and enhance the use of gathered information with creativity. Converging emphasizes problem-solving with applied learning. Lastly, assimilating occurs when the learner encounters new information they try to fit into the web of their preexisting knowledge. These four learning types are identified along two bipolar dimensions: active-to-reflective (doing-watching) and concrete-to-abstract (feeling-thinking). Learners that are more active and concrete are considered accommodators, and so on, following the diagram above (Cornwell & Manfredo, 1994).

Neuroscience research has consistently supported the effectiveness of experiential learning as a key learning method. Cited in the Journal of Experiential Education, the authors write that "experiential learning integrates different neural networks during the learning event" (Piaget, 1950/2001), resulting in multiple memory pathways (Hebb, 1949) and connections between abstract concepts. The neural networks referred to are the different sensory channels (auditory and visual stimuli), kinesthetic stimuli (moving), and experience-based memory pathways, such as episodic memory. The combination of these different encoding pathways while actively learning in an immersive environment aid in stronger memory retention. When students develop demonstrations of these abstract concepts or explain them through multiple modalities, there is a significantly higher retention rate (Craik & Tulving, 1975). Multiple neural pathways encoding information is more effective for long-term memory and retention compared to practicing a strict "learning style" where a single approach limits the student. Furthermore, experiential learning offers opportunities for novel experiences vital for memory formation. The literature review will touch on this phenomenon more in the following text.

3 THE ROLE OF SENSORY STIMULATION IN EXPERIENTIAL LEARNING (EL)/VR

Multisensory aspects of experiences are essential for EL and aid furthermore in the retention process. Creating realistic experiences in virtual reality environments aims to foster brain and behavioral responses in the virtual world that are analogous to those in the real world. For instance, researchers have been able to view the sensorimotor system in a more controlled environment, which would not have been possible in real-world experiments. Although the quantifiable results of studies on this system are irrelevant to the scope of this paper, it is essential to note the accessibility of studying the sensory-motor system in a controlled environment while a patient wears a VR hardware piece. The sensorimotor system is a network of neurons that includes the body's nervous system, sensory organs, and motor controls. When stimulated by a digital environment containing triggering stimuli, it is easier to measure this system in action. At the same time, the patient remains in the same location instead of the patient out in the world.

In a study from Georgia Tech University presented at the Institute of Electrical and Electronics Engineers (IEEE) Annual International Symposium Virtual Reality, 322 subjects participated in an experimental study. The study investigated the effects of tactile (touch), olfactory (smell), audio (hearing), and visual (sight) sensory cues on a participant's sense of presence in a virtual environment by placing the participants in a simulated corporate office suite and varying these sensory cues. There were four primary dependent variables: one question on the overall rating of presence (range from 0 to 100), a longer 13-item presence questionnaire, a four-item questionnaire on the spatial layout, and a five-item questionnaire on object location. The participant's memory was also tested on the objects in that environment (testing recall and retention). Results strongly indicate that increasing the different sensory modalities in a virtual environment can increase both the sense of presence and memory for objects in the environment (Dinh et al.).

The paper *From Presence to Consciousness through Virtual Reality* by Maria V. Sanchez-Vives and Mel Slater further explores the concept of the presence or the feeling of "being there." To take this further, consider "telepresence," first introduced by Minsky in 1980. Telepresence is seen when the user acquires the sense that they are immersed in a different environment than reality. For instance, a user of virtual reality technology sees through the eyes of a headset and uses their arms and legs to control ingame movements. Here, the machine "body" replaces one's true self. The user is immersed in an environment with similar bodily controls to reality, developing the phenomena of telepresence. Similarly, "virtualization" occurs when the user interprets a virtual image as a real object without anything physically being there. By immersing a user in a virtual space with virtualization and sensory stimuli, telepresence becomes possible.

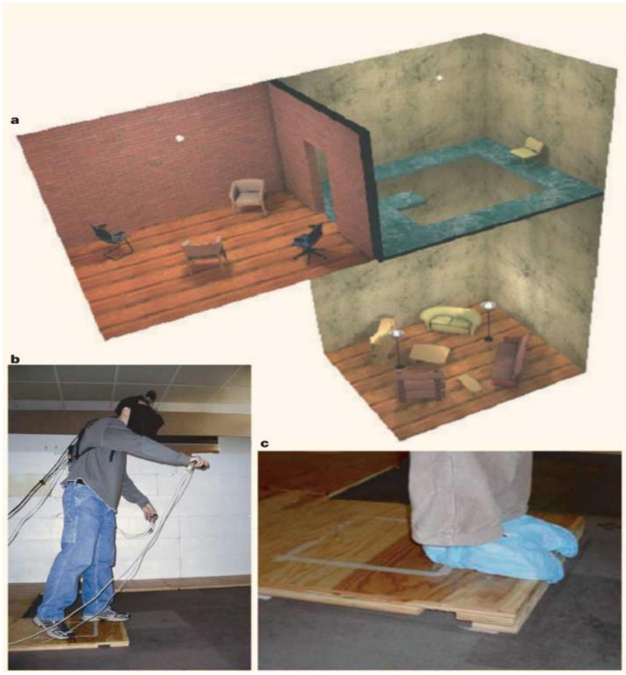

FIGURE 2: *Early visualizations (top) and the physical setup (bottom) of telepresence*

The diagram above illustrates a user experiencing a virtual environment, yet responding to stimuli as if it was real, not virtual. Tactile stimuli of a floorboard's edge, accompanied by visuals of a deep precipice, cause the user's heart to race; this paradox is at the root of the concept of presence.

Audio stimuli are one of the sensory channels of encoding external input for an individual and are especially strong when an individual is attentive to their environment. Since VR technology is especially skilled at providing a user with audio and visual stimuli for an immersive digital experience, it is important to delve into the contributions of audio stimuli for presence within a VR environment.

Spatialized sound, or a surround sound effect, significantly increases the sense of presence in a virtual environment by creating realistic auditory cues. (Hendrix & Barfield, 1996). This phenomenon is commonly called the soundscape or the acoustic environment humans perceive in a particular context. A soundscape encompasses the entire aroma of an environment, including natural or mechanical sounds. A soundscape is beneficial because of the increased immersion and telepresence a user feels, which is necessary for enhancing experiential learning in VR.

To further investigate audio sensory stimuli, a 2020 study in the Journal of Frontiers in Robotics and AI compared walking in a virtual park with a soundscape vs. self-triggered footsteps. The publication demonstrated that auditory perception can "compensate for restricted visual fields of view" (Kern and Ellermeier, 2020), or limitations of visual stimuli. Two features were studied within the environment: the soundscape, consisting of ambient nature audio, and footsteps, corresponding to walking audio. During the experience, the participants were asked to count specified objects in the environment. As a result, the background soundscape aided in a higher sense of presence, immersion, and involvement in addition to lower distractions, compared to distinct footsteps. The study stressed that "presence is enhanced by the reproduction of sound", with effective soundscape sounds serving as three times more effective in creating a more subtle, holistic immersion. *The Effects of Student Engagement, Satisfaction, and Perceived Learning in Online Learning Environments* bridges these results to classroom learning. A survey of 216 graduate students revealed a .652 correlation between learner interaction and student engagement and a .403 correlation between instructor presence and student engagement. The study then explored a .891 correlation between student engagement and perceived student learning (Gray and DiLoreto, 2016). Interaction and learning were "fully mediated by student engagement," demonstrating a statistically significant link between engaged students and classroom learning. These phenomena may be a valuable consideration for designers of VR environments in the future, emphasizing the importance of audio-sensory stimuli and their influence on higher presence and user engagement.

4 MAYER'S COGNITIVE THEORY OF MULTIMEDIA LEARNING

Now that the fundamentals of experiential learning have been reviewed, the literature review will move into education theorist Richard Mayer and his theory on Multimedia Learning styles. The de facto source on this is the *Cognitive Theory of Multimedia Learning* by Richard E. Mayer states his theory very as being rooted in three cognitive science principles of learning:

The dual-channel assumption: the assumption that human information processing systems include dual channels for visual and auditory information, respectively.

The limited capacity assumption: the assumption that every human has a limited capacity for processing information.

The Active Processing Assumption: the assumption that active learning requires carrying out a coordinated set of processes.

The rationale behind the multimedia learning theory is that humans learn more deeply from words and pictures than words alone, and our scope of multimedia consumption is immensely growing. Mayer's theory outlines how one might effectively present information through multimedia formats, dubbing the term "multimedia design."

This leads to the next logical question. How can different multimedia formats be used to promote learning? In multimedia instructional environments, learners are exposed to a variety of text and visual materials, including static and dynamic forms (Mayer and Moreno, 2002). Animation is one of these forms of dynamic pictorial multimedia, referring to a "*simulated motion picture* depicting the movement of drawn (or simulated) objects." In this study, Mayer and Moreno, based on their research, created a collection of seven principles for multimedia animation design by comparing the problem-solving transfer performance with and without certain conditions; These seven principles are *Multimedia, Spatial Contiguity, Temporal Contiguity, Coherence, Modality, Redundancy, and Personalization*. These allow the measurement of the students' ability to use what they have learned in new situations, creating a framework for designing animations, narrations, and other multimedia content.

There have been multiple attempts to test the instructional effectiveness of immersive virtual reality against traditional instructional effectiveness. In a study conducted by Richard Mayer and Jocelyn Parong, the effectiveness of virtual reality in learning science was explored through two experiments, one comparing VR with traditional slideshow learning content (to mimic traditional instructional environments) and the other comparing segmented VR with individual lesson summaries (referred to as VR+) versus continuous VR lessons. Mayer and Parong examined mean post-test scores and self-reported engagement, interest, and motivation levels. They found that students who viewed a slideshow scored higher on a post-test (M = 13.54 versus M = 10.17) but showed lower levels of interest, motivation, and engagement ratings compared to the other group. Experiment 2 showed that the VR+ learning experience produced significantly better results on the post-test than VR (M = 13.84 versus M = 10.31), while the groups did not differ in interest, engagement, and motivation. An interesting point to consider is that the VR learners performed as well as slideshow learners in conceptual questions but lacked only terms of factual questions. This supports the cognitive theory of multimedia learning and demonstrates the value of generative learning (learning both physically and cognitively actively in organizing and integrating new information into existing knowledge structures) strategies in immersive VR environments (Parong, Mayer, 2018). However, further research needs to be conducted with Mayer's theory of multimedia learning and design principles to study the effectiveness of segmented and supplemental VR content to combine multiple multimedia formats of educational content into Kolb's experiential learning model.

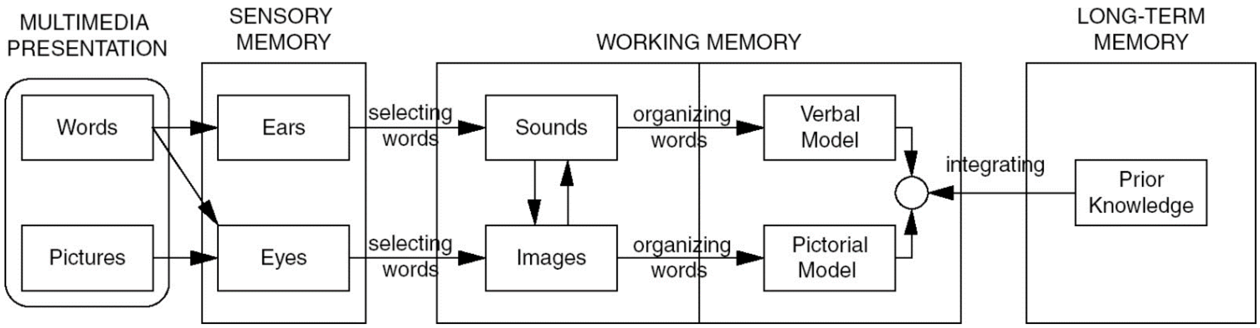

FIGURE 3: *Conceptual model of the cognitive theory of multimedia learning, from the Cambridge Handbook of Multimedia Learning, pp. 43 – 7*

5 COMMENTS ON THE LITERATURE AND THE APPLICATIONS OF THE RESEARCH

Looking back on the literature compiled, the need for continued research to be done on the effectiveness of experiential learning content and multimedia design in educational multimedia formats, especially future technological formats such as Virtual Reality (VR), Augmented Reality (AR) and Extended/Mixed Reality (XR), is recognized. Augmented reality is a digital experience that enhances the real world through modification and digital projection, while Extended/Mixed Reality combines VR and AR.

Virtual, augmented, and mixed reality provides a wide range of possible applications to bring users into a fully immersive environment that might not otherwise be accessible. In fact, many corporations have turned to XR for corporate training. Experiential learning is a powerful form of learning that can be effectively utilized through virtual reality, such as taking field trips or having other inaccessible or expensive experiences. However, as previously mentioned, one would need to study the short and long-term effects of virtual reality education and content retention. These effects can be anywhere from headaches/migraines, non-effective learning, or increased distractions to hindered problem-solving ability, dependence on movement to learn, or shortened attention span, amongst countless other possibilities.

Furthermore, based on Mayer's Cognitive Theory of Multimedia Learning, education is supercharged when presented in multiple formats, and therefore, virtual reality would need to be paired with other media formats for full effectiveness. Based on the literature presented, it is hypothesized that segmented VR learning designed with the multimedia principles outlined above, paired with reflection exercises such as summarizing content and posttests, can drastically increase learning effectiveness and retention by promoting conceptual learning and increased engagement. There is an incredible importance of research in bridging the two educational theories, Kolb's model of Experiential Learning and Mayer's Cognitive Theory of Multimedia Learning, and it is exciting to see what future literature and research hold ■

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