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Exploring the Potential of Virtual Reality for Learning –A Systematic Literature Review

Sebastian Weber[1]

Contact: Sebastian Weber, University of Siegen, sebastian.weber@uni-siegen.de

[1] University of Siegen, Siegen, Germany

Abstract. With the recent advent of affordable consumer technologies like Oculus Rift and gadgets from other technology companies as HTC, Google, or Samsung, virtual reality has gained enormous popularity. Offering unique characteristics like the feeling of being in a virtual space and a natural interaction with objects in this space, virtual reality has also been part of research as a promising learning tool. However, results in this context are mixed. Using the approach of a systematic literature review, this research scrutinizes these different results and contradictory theories. The outcomes present which theoretical approaches have been taken to explain learning and which factors are essential regarding the design of a virtual space. Furthermore, this research identifies future research opportunities to better understand and unfold the potential of virtual reality for learning.

Keywords: Virtual Reality, Individual Learning, Learning Theories, Systematic Review, Literature Review

1 Introduction

Trying to understand the process of learning has a long tradition (Illeris, 2018; Schunk, 2012). This is also reflected in the different streams and paradigms of philosophy, psychology, or neuroscience, which try to understand learning and to explain how the human mind works (Schunk, 2012). The rationale behind this endeavor is to gather a more profound understanding and enable a better instructional design that fosters knowledge acquisition. The idea of using Information Technology (IT) in this frame of reference is not new. It was conceived in the 1940s when Bush introduced the concept of his well-known 'Memex' (Bush, 1945). With further expansion and development (Baskerville, 2011), IT also played an increasingly important role in the context of learning. In particular Virtual Reality (VR), with its unique features and accessibility today offers the possibility to create new opportunities that support learning. One of the most powerful features in favor of VR is its ability to create a perceptual illusion (i.e., a feeling of being in a virtual space; Slater, 2018). Furthermore, the VR devices provide controllers to interact within VR (Anthes et al., 2016). These allow tracking and natural interaction with objects like in the real world (Nanjappan et al., 2018). Thus, VR offers the benefit of interactive experiences that enable active learning without distraction (Martín-Gutiérrez et al., 2017). For example, it is possible to immerse in VR and train in dangerous environments (Lathan et al., 2002), visualize scenarios that are not visible in the real world (Kampling, 2018b), or train and test psychomotor skills before they can be used in the real world (Aggarwal et al., 2006). However, results on learning in VR are mixed. As such, my research objective is to provide a systematic synthesis of which theoretical approaches have been taken that explain learning in VR and what are distinct factors that influence the learning success. In this way, I would like to provide an essential foundation on which researchers and practitioners can draw from. Practitioners can use the insights to design VR scenarios in such a way that the technology can unleash its full potential as a learning tool, and researchers can use it to gain an overview to facilitate future theory development.

In order to address the objectives, the remainder of this paper is structured as follows: In section two, I briefly review the technology and concept of VR as well as an overview of learning in VR. Then, I explain the methodological approach in detail. Section four presents the results. I conclude by discussing the findings in section five.

2 Related Work

Since the advent of Oculus Rift and gadgets from other technology companies as HTC, Google, or Samsung, affordable and immersive consumer technologies became omnipresent (Castelvecchi, 2016). These VR devices are often multi-sensory, head-mounted displays (HMDs) (Anthes et al., 2016). The HMDs have a head tracking system that updates the left and right vision (i.e., the stereo vision) to match the user's head movements within VR (Slater, 2009). Integrated headphones deliver audio (Slater, 2009)[2]. The concept of VR is besides its technological components (i.e., software and hardware to create a 3D environment) mainly characterized by three features, namely immersion, the feeling of being present in VR, and interaction with the VR environment. This is also reflected in the definitions. Wexelblat (1993), for example, described VR as a computer-generated, interactive, 3D environment in which people become immersed. Gigante (1993) characterized VR as: "*The illusion of participation in a synthetic environment rather than external observation of such an environment. VR relies on a 3D, stereoscopic head-tracker displays, hand/body tracking, and binaural sound. VR is an immersive, multi-sensory experience*" (p. 3). Burdea and Coiffet (2003) defined VR as "*a high-end user-computer interface that involves realtime simulation and interactions through multiple sensorial channels. These sensorial modalities are visual, auditory, tactile, smell, and taste*" (p. 3). Moreover, Riva (2007) defines VR, as "*a simulated environment in which a perceiver experiences the feeling of presence by means of a communication medium, a phenomenon referred to as telepresence*" (p. 1240). These features are also the reason why VR is unique and seen as promising in the context of learning [3].

In this respect, it is not surprising that a multitude of theoretical approaches was used to compare VR with other media and to examine specific design aspects. However, the results of learning in VR are mixed. While one stream presents VR as a superior media format for learning (e.g., Butavicius et al., 2012; Dubovi et al., 2017; Lee & Wong, 2014), another stream does not confirm these results (e.g., Leder et al., 2019; Makransky, Terkildsen, & Mayer, 2019; Parong & Mayer, 2018). The present study, therefore, attempts to shed some light on the issue by providing and reviewing the status quo.

3 Methodology

To achieve the objectives, I conducted a systematic literature review (Boell & Cecez-Kecmanovic, 2015; vom Brocke et al., 2009;

[2] For a for a state-of-the-art review of the technology see Anthes et al. (2016).

[3] See Slater (2009) and Schultze (2010) for a comprehensive description of the conceptual properties of VR.

Webster & Watson, 2002) and followed a proposed five-step procedure as suggested by vom Brocke et al. (2009).

(1) In the first step, I used the taxonomy of Cooper (1988) to define the review scope. According to this taxonomy, I mainly focus on the research outcomes but also on the other areas. The goal of the review is to synthesize and to integrate findings of prior work on learning in VR to purvey a status quo and to give advice on how scholars can further extend the current body of knowledge. Since I am interested in learning in VR, I organize the results conceptually (i.e., used theories and concepts). To achieve this goal, I espouse a neutral perspective to inform general and specialized scholars as well as practitioners on learning in VR. Furthermore, the review aims to representatively cover pivotal learning research on VR by including the databases Business Source Complete, PsycInfo, PsycArticles, and AISeL. I focused on these databases because they cover a substantial body of knowledge within the IS field and also educational psychology.

(2) In the second step, it is suggested to give a broad conception of the topic. Therefore, I provided a brief overview in the previous chapter.

(3) Step three involves the literature search. The search included the databases Business Source Complete, PsycInfo, and PsycArticles, which were accessed via EBSCOHost. I furthermore included the database AISeL (accessed via the website: https://aisel.aisnet.org/) to cover further related IS (Information Systems) work on learning in VR. To find relevant papers, I chose the search term 'learning' and 'virtual reality' (search string: TI "learning" AND TI "virtual reality"). I used the keyword 'learning' because there is no uniform term for the measurement of learning outcomes. Thus, 'learning' ensures that several variations (e.g., learning effectiveness or learning performance) are included. The search was focused on searching the keywords within the title and was limited to publications within the last ten years to retrieve only related and current research. I am aware that this strategy may exclude some relevant results, but as I am mainly focused on the current results of learning in VR, these keywords should be mostly contained within the title of relevant work. The literature search was conducted between July 2019 and December 2019 and yielded initially 95 hits (EBSCOHost: 88 hits; AISeL: 7 hits). Then, I filtered the search results to peer-reviewed scientific articles (72 hits left – exclusion of 22 hits in EBSCOHost) and excluded research that was not published in English (71 hits left – exclusion of 1 hit in EBSCOHost) via the EBSCOHost filters and in AISeL manually. After skipping duplicates (2 duplicates in EBSCOHost), 69 articles remained. Then, each article was scrutinized with a focus on the abstract, participants, procedure, and learning measurement. Based on this reading, further 42 articles that did not meet the inclusion criteria were excluded (see **Fehler! Verweisquelle konnte nicht gefunden werden.** for all inclusion-/exclusion criteria). In total, 27 articles were left after this scanning procedure. These 27 articles were then selected for cataloging and thorough reading. Each article was presented by its journal, author(s), theoretical approach(es), research objective(s), the domain of learning, measurement approach of learning, factors influencing learning, and the used VR technology.

Inclusion criteria	**Exclusion criteria**
Peer-reviewed research	Nonscientific source
The article is written in English	The article is not written in English
The article examines learning in 3D-VR	The article does not examine learning in 3D-VR

The article provides empirical results on learning	The article does not provide empirical results on learning
Sample without special needs	Sample with special needs

Table 3. Inclusion and exclusion criteria

(4) Step four deals with the analysis and synthesis of the relevant literature. To analyze literature on learning in VR, I scrutinized factors making learning in VR different from learning in other environments. Particularly, I analyzed the theoretical approaches as well as the results to inform about factors influencing learning in VR. To do so, I only considered theories that were a) undermined with an explanation of how they may affect learning and b) included measurement of the underlying constructs. The results are presented in the following chapter 4.

(5) The last step of a review is the formulation of a research agenda. The agenda is provided in the discussion in chapter 5.

4 Results

The examined research used several approaches to explain learning in VR. On the one hand, medium-independent learning theories have been investigated to compare different media. On the other hand, theories and concepts have investigated specific forms of learning or design aspects in VR. In the following, I briefly introduce all the theories and concepts used and show related results:

Cognitive Load Theory (CLT) & Cognitive Theory of Multimedia Learning (CTML). The CLT proposes that capacity in the working memory is limited (Sweller et al., 2011). The cognitive load refers to the total amount of resources needed to process information (Sweller et al., 2011). The theory distinguishes three types of cognitive load: intrinsic cognitive load, germane cognitive load, and extraneous cognitive load (Sweller et al., 2011). The intrinsic cognitive load refers to the loads created by the difficulty levels of teaching materials for learners and is difficult to manipulate by the instructional design (Sweller et al., 1998). The extraneous cognitive load is induced by the learning material or the type of media presentation, which can be changed by instructional designs (Sweller et al., 1998). The germane cognitive load is linked to learners' degree of concentration and ability of schema acquisition that are affected by the organization of teaching material and type of media presentation (Paas et al., 2003). Hence, it can also be altered by instructional design (Paas et al., 2003). In order to process information properly, memory resources should not be exceeded (Sweller et al., 2011). CTML builds upon the CLT and assumes that humans process information in separate channels (i.e., an auditorial/verbal channel for narration, sounds, etc. and a visual/pictorial channel for animations, videos, etc.), have a limited capacity in working memory (i.e., they can only process a limited amount of information per channel at one time) and that meaningful learning requires active cognitive processing (Mayer, 2009). Based on this, the theory derived several principles (12 principles in total) to optimize instruction according to the mentioned assumptions (cf. Mayer, 2009). Makransky, Terkildsen, and Mayer (2019) and Parong and Mayer (2018) argue based on the CTML that high immersive VR requires higher cognitive load (because of more extraneous details) and thus focus on important facts is decreased. These studies showed indeed that high immersive VR yields higher cognitive load and is less effective in learning than with presentation slides (Parong & Mayer, 2018) or in a PC Lab (desktop VR) (Makransky, Terkildsen, & Mayer, 2019). This is in line with the coherence principle (i.e., people learn better when extraneous material is excluded) of the CTML. However, it has been shown that this effect can be repealed by applying the segmenting principle (i.e., learning material should be presented in user-paced segments rather than a continuous unit), which enables better processing of information (Parong & Mayer, 2018). Research has also shown that VR does not always lead to a higher cognitive load. Lee and Wong (2014) showed the opposite for low-spatial ability learners. In this case, learning with desktop VR is better than with presentation slides. They explain this issue with a higher extraneous cognitive load resulting from the transformation of 2D objects into 3D in the slideshow, suggesting an aptitude-treatment-interaction. Furthermore, Kartiko et al. (2010) found that the visual complexity of animated virtual characters is not a crucial facet that influences cognitive load and learning. Other results of the CTML highlight that the redundancy principle (i.e., animation and narration yields better learning than learning with additional visual text information) was not supported in VR (Makransky, Terkildsen, & Mayer, 2019). Makransky, Terkildsen, and Mayer (2019) argue that the design could have been responsible for the results (i.e., students just listened instead of reading, which is also supported by results of the cognitive load).

Interest Theory (INT). Parong and Mayer (2018) further investigated INT as an opposing approach, which proposes that learners learn more intensively when they value the content or are elicited by the situation (Dewey, 1913). The rationale behind this idea is that VR could be able to foster situational interest, which would yield deeper processing of the learning material. However, while immersive VR can enhance motivation, engagement, and enjoyment, it was not superior in terms of learning (Parong & Mayer, 2018).

Embodied Cognition (EC). An additional cognitive approach to explain learning is EC. Often it refers to the role of the body as 'conditio sine qua non', meaning that "*aspects of the agent's body beyond the brain play a significant causal or physically constitutive role in cognitive processing*" (R. A. Wilson & Foglia, 2019). However, there are several views on EC (M. Wilson, 2002) . Yuviler-Gavish et al. (2014) examined embodied cognition in terms of observational learning. Based on the hypothesis 'cognition is for action', they argue that the visual system can prime motor functions. Results show that in comparison to an enactive approach (i.e., performing physical action), partly observational learning (i.e., performing only a specific task of the whole procedure) is equal in learning performance (i.e., errors at a real-world task) but more efficient (i.e., less time consuming). However, Jang et al. (2017) found in a yoked-pair design that direct manipulation of an anatomic structure promotes better learning (i.e., participants were able to reconstruct/draw better the structure) than merely observing. They assume that direct manipulation yielded alignment between the perceived structure and one's own body, which in turn facilitates learning. Gordon et al. (2019) also observed that both forms, learning through sensorimotor experience as well as observation (albeit less), promote language learning. Besides, with a different focus, Markowitz et al. (2018) argue that 'cognition is situated' and immersive VR supports situated action. Therefore, they exploratively investigated different forms of self-avatars to see if a particular avatar embodiment engages the user to create stronger social and psychological attachments to an environment and thus increases learning. However, results did not yield any differences in learning outcomes.

Interactive Information Processing Model (IIPM). In contrast, the idea of Markowitz et al. (2018) bases on an interactive information process, assuming that interactivity with media, elaborative cognitive processing, and information recall are positively associated (Tremayne & Dunwoody, 2001). Their results support this assumption. They show that more interactive participants (more exploration of VR environment) achieve better learning success.

Reward-Based Learning (RBL). RBL can be described as a reinforced positive feedback loop (i.e., the desired action is associated with a reward which forms a positive loop; Bourgeois et al., 2018). Two studies that used this approach showed that rewards could be an element to foster learning in VR (Bourgeois et al., 2018; Marsh et al., 2010). Interestingly, however, the spatial placement of the rewards seems to play a crucial role, as there are biases (rewards on the left side are better recognized; Bourgeois et al., 2018).

Matching Hypothesis (MH). The MH of Makransky, Wismer, and Mayer (2019) states that a pedagogical agent in VR can enhance learning if the learner can identify with her/him. Results indicate that if the pedagogical agent matches the learner characteristics (e.g., by gender), then the learning outcomes are better.

Presence. The characteristic of presence is generally the rationale for using immersive VR for learning. Accordingly, research frequently included this concept. Presence is often described as the illusion or the feeling of being there (Schultze, 2010). The results in terms of learning are mixed. While some studies report a positive influence on learning (Dubovi et al., 2017; Kampling, 2018a, 2018b; Lee et al., 2010; Markowitz et al., 2018) other do not report an effect (Kartiko et al., 2010; Leder et al., 2019; Makransky, Terkildsen, & Mayer, 2019).

Immersion. A further approach used was cognitive absorption or, more precisely, the sub-dimension immersion. It is described as an experience of total engagement (Agarwal & Karahanna, 2000). The results show mixed results (Kampling, 2018a, 2018b; Kampling et al., 2019). On the one hand, quantitative results show that this concept does negatively affect learning (Kampling, 2018a). In detail, it was shown that immersion does not have an influence on learning performance but a negative effect on perceived learning effectiveness. On the other hand, qualitative insights suggest a positive impact on learning (Kampling, 2018b; Kampling et al., 2019).

5 Discussion

First of all, literature shows that there is still a lack of research on learning in immersive VR. Regarding the technology, it is surprising that only 13 of the examined 27 papers used immersion supporting technologies like a HMD (e.g., HTC Vive, Oculus Rift, Samsung Gear VR) or CAVE in the last ten years.

Second, the results on learning in VR are mixed, and research used a plethora of theoretical approaches to explain different aspects of learning in VR. On the one hand, immersive VR shapes a feeling of presence (e.g., Kampling, 2018a; Makransky, Wismer, & Mayer, 2019; Markowitz et al., 2018), yielding total engagement with VR (e.g., Kampling, 2018a). Therefore, attention is entirely focused on VR, and distractors are suppressed (Kampling, 2018a; Martín-Gutiérrez et al., 2017), which improves learning (e.g., Kampling, 2018b; Markowitz et al., 2018). On the other hand, theories like the CLT and CTML propose that immersive VR induces higher extraneous cognitive load, which in turn decreases learning (Makransky, Terkildsen, & Mayer, 2019; Mayer, 2009). Makransky, Terkildsen, and Mayer assume that "*added immersion can interfere with reflection as the entertainment value of the environment does not give the learner ample time to cognitively assimilate new information to existing schemas*" (Makransky, Terkildsen, & Mayer, 2019, pp. 233–234). However, both explanations show mixed results as highlighted in chapter 4. As such, VR can be considered as a promising tool for learning if specific factors are taken into account. In particular, against the backdrop that immersive VR is more motivating and engaging than non-immersive media (e.g., Makransky, Terkildsen, & Mayer, 2019; Parong & Mayer, 2018). This should not be neglected as there is evidence that situational interest can be a first step in promoting learning (Renninger & Hidi, 2016).

Overall, these results suggest that further research needed to use the power of immersive VR without inducing too much extraneous cognitive load. In this line, for example, I would suggest combining VR and eye-tracking to objectively identify cognitively distracting and overstraining factors within VR. Also, in the light of the concept of social presence (Schultze & Brooks, 2019) and the findings of the MH (Makransky, Wismer, & Mayer, 2019), it should be further investigated which other characteristics of an avatar, taking into account demographic variables, positively influence learning outcomes. In addition, future research should include longitudinal studies to evaluate motivation and learning outcomes over time. Finally, the context in which learning took place was mostly scientific learning. As Parong and Mayer (2018) also suggest, research should include other teaching materials and further authentic learning settings.

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