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What Are You Looking At? Using Eye Tracking to improve Learning in Virtual Environments

Michael Schlechtinger[1]

Contact: Michael Schlechtinger, University of Siegen, michael.schlechtinger@uni-siegen.de

[1] University of Siegen, Siegen, Germany

Abstract. Learning in Virtual Reality (VR) is an emerging topic characterized by opposing theories. The interest theory hypothesizes that students who learned in immersive VR would report more positive ratings of interest and motivation and would thus score higher on a test covering the lesson learned. On the other hand, the cognitive theory of multimedia learning assumes that students who learned with a classic medium would score higher on a test covering the lesson learned, while reporting lower in terms of interest and motivation. In this proposal, I focus on the concept of learning in VR, which is an emerging concept in information science (IS) research that can be studied using neurological measures such as eye tracking. While previous literature has provided initial evidence of the feasibility of eye tracking in a learning context, this study seeks to investigate how well eye tracking performs when it comes to detecting items inducing superfluous cognitive load in a VR setting.

Keywords: Virtual Reality, Eye Tracking, Learning, Cognitive Load, Knowledge Transfer

1 Introduction

Philosophy, psychology or, neuroscience; the main body of studies within the cognitive science research draws from education and learning research in order to explain how the human mind works (Schunk, 2009). A major goal is to bridge the gap between the fields through a direct dialogue between researchers and educators, thus enabling a better instructional design of the factors that stimulate knowledge acquisition.

IS-Research on the other hand tries to use the knowledge gained from education and learning research to apply it to new forms of media. VR offers the benefit of unique experiences that enable active learning without distraction (Martín-Gutiérrez et al., 2017). Some researchers describe immersive VR as a more motivating and engaging learning medium compared to non-immersive media (e.g., Makransky, Terkildsen, & Mayer, 2019; Parong & Mayer, 2018). Other researchers claim that VR creates additional cognitive load induced by superfluous visual effects, hence reducing the learner's performance (Makransky, Terkildsen, & Mayer, 2019; Mayer, 2014; Parong & Mayer, 2018).

Many head-mounted displays (HMDs) have integrated sensors to track the position and orientation of the user as well as their hand positions measured by the controller in the virtual space (Siegrist et al., 2019). However, only few research has taken advantage of eye tracking in combination with consumer-HMDs to expand its use beyond desktop computers (Vasseur et al., 2019).

The quantifiable data gathered from gaze detection can help us to improve virtual learning scenarios by promoting visual expertise with the generation of eye movement modeling examples (Holmqvist et al., 2017; Zhao et al., 2017). To better understand the concept of learning in VR, this study proposes an experiment to use eye tracking in order to improve learning material by detecting cognitive load inducing factors. The remainder is structured as follows: First, I briefly review the concept of learning in the context of VR and how it is measured (section 2). In section 3, I propose an experimental setting that allows me to investigate VR-learning scenarios with the help of eye tracking. I conclude by reflecting on potential insights and future directions of this research.

2 Related Work

Few studies propose that immersive VR and the feeling of presence yield worse learning outcomes than non-immersive media (such as Microsoft PowerPoint slides) (Makransky, Terkildsen, & Mayer, 2019). The cognitive theory of multimedia learning (Mayer, 2009, 2014) as well as the cognitive load theory (Sweller et al., 2011) attribute extraneous processing to VR-usage. Features, such as additionally induced visual effects evoke cognitive processing that is not relevant to the instructional goal.

However, competing theories exist. For instance interest theory suggest that students learn more intensively when they value the content or are elicited by the situation (Dewey, 1913). Researchers that probed for learning interest and motivation in line with these theories and restructured their experiments accordingly, were able to achieve learning success in an immersive VR-environment (e.g., Kampling, 2018; Markowitz et al., 2018; Parong & Mayer, 2018). As such, Parong and Mayer (2018) performed experiments while adjusting specific factors to apply the cognitive theory of multimedia learning as well as the interest theory to result in a successful, highly motivational learning experience. In order to acquire data of excessive cognitive processing, while still providing the motivational aspect of VR, the user's attention within the software has to be measured.

Literature uses eye tracking to analyze attention in a learning context. I summarized the results of my literature analysis in Table 1, confirming that eye tracking performed on a desktop computer is rather common in IS literature, yet only little research has been done to analyze mobile eye tracking in a similar context (Vasseur et al., 2019). Since VR-eye tracking provides the respondent with full flexibility regarding natural movements in a fully immersive 3D environment, a combination of the strengths of mobile and desktop-based eye tracking can be achieved (Meißner et al., 2019). In order to fully benefit from mobile eye tracking, I excluded literature that used Cave Automatic Virtual Environment (CAVE) devices as they restrict the space of movement, are unaffordable for most consumers compared to HMD devices, yet do not provide significant advantages in terms of immersion (Mallaro et al., 2017). VR eye tracking literature that uses HMDs is scarce. My findings mostly confine to examinations of VR eye tracking fundamentals, including challenges, alleviation of usability issues as well as setup, optimizations (Clay et al., 2019; McNamara & Jain, 2019). As such, Clay et al., (2019) describe the process of bringing VR in combination with eye tracking into the lab in order to inspire ideas for new experiments. Few studies performed experiments to acquire quantitative data from VR-eye tracking (Clay et al., 2019; Duchowski et al., 2000; Khamis et al., 2018). Nevertheless, none of the presented research analyzed virtual environments using eye tracking with the goal of learning performance maximization.

A large set of research focussed on learning or attention detection using eye tracking (see Table 1). Large proportions dealt with the risks of automobile crashes due to unmindfulness especially in context of autonomous driving (Hatfield et al., 2019; He et al., 2011; Huang et al., 2019). Other researchers also probing for attention tasks, familiarized test subjects with massive open online courses. Arguing from a perspective of the working memory, Zhao et al. (2017), successfully used eye tracking to improve the instructional design of computer-based learning and testing environments. Additionally, research within the Educational Science domain more and more uses eye tracking to shed light on expertise and its development in visual domains as well as promote visual expertise by means of eye movement modeling examples (Holmqvist et al., 2017).

The opposing ideologies 'interest theory' and 'cognitive theory of multimedia learning' suggest that learning in VR will motivate students to work harder while cognitive overload will hinder their learning success. As Educational Science research suggests, eye tracking can be used to create better learning material by detecting items that create superfluous cognitive load (Holmqvist et al., 2017; Zhao et al., 2017). With the following experimental setting I seek to research virtual environment fidelity settings that allow for an improvement of learning performance detected by using eye tracking data.

VR	Learning	Eye Tracking	Example references
✓	✓		(Butavicius et al., 2012; Gordon et al., 2019; Kampling, 2018; Kampling et al., 2019; Makransky, Terkildsen, & Mayer, 2019; Makransky, Wismer, & Mayer, 2019; Markowitz et al., 2018; Parong & Mayer, 2018; Sense & van Rijn, 2018)
✓		✓	(Clay et al., 2019; Duchowski et al., 2000; Khamis et al., 2018; McNamara & Jain, 2019; Siegrist et al., 2019)
	✓	✓	(Gwizdka, 2019; Hatfield et al., 2019; He et al., 2011; Holmqvist et al., 2017; Huang et al., 2019; Hutt et al., 2016; Hutt et al., 2019; Reichle et al., 2010; Robison et al., 2017; Steindorf & Rummel, 2020)
✓	✓	✓	**(this study)**

Table 2 Literature analysis

3 Methods

60 experimentees will be assigned to one of two groups. Both groups will be assigned to participate in a guided crane maintenance task. One group will benefit from the detailed environments with high quality textures, while the other group will experience an environment that has been reduced to only the crane as well as the necessary tools. Stimuli delivery and eye tracking will be conducted using HTC Vive PRO Eye SRanipal SDK, will be developed using the Unity engine and delivered using SteamVR. Participants will be screened for normal or corrected-to-normal eyesight, use of upper limbs and proficiency in English or German. Subjects will be informed that we are investigating their gaze in a simulated work environment. I will seek approval from our university's research ethics board and each session will last for 30 minutes in a controlled setting. At the completion of each session, participants will receive 15€.

3.1 Procedure and Materials

Experimentees will undergo a consent protocol, complete an initial demographic questionnaire, will then be fitted with the HTC Vive PRO Eye VR-system and undergo a calibration routine. Participants will then take part in a virtual crane maintenance task. The subjects will find themselves in a harbor setting with a crane that is only accessible from the side of the brink, otherwise surrounded by cargo. The high fidelity group, however will additionally see some boats, ships and yachts in the background moving across the harbor. Both groups are given a series of gradual, textual instructions which will guide the subjects through the different maintenance steps (e.g., visual examination or applying grease to the chain), each comprised of several substeps. Following the VR session, participants will undergo a debriefing.

3.2 Questionnaires and Physiological Measures

As suggested by Peper & Mayer (1986) or Coleman et al., (1997), the subjects will be interrupted after every step in order to summarize the procedure. This shall increase the learning outcome. Following the experiment, participants will complete a postquestionnaire to make self-ratings about their effort and understanding, their motivation, their interest for the subject, their engagement with the lesson, and their mood (Parong & Mayer, 2018). Followed by the questionnaire, subjects will complete a posttest with 20 questions based on the lesson.

Additionally, performance related indicators such as maintenance time, execution precision, tool waste, as well as task success will be recorded by the software. Eye tracking behavior will be analyzed in 2 second epochs preceding each event. Epochs will be investigated for pupil diameter, gaze fixation, search behavior and task completion time.

3.3 Data Analysis

Each participant is expected to yield between 5000 and 7000 epochs. Multivariate linear regression will be used to assess the effects of the measures reported. The acquired gaze data will be mapped to the posttest results as well as the information gathered by the software itself.

4 Outlook

Although the field of VR learning is growing, research is short of "experimental quantitative approach[es]" (Kampling et al., 2019). Consequently, this study seeks to extend current insights in terms of how to improve VR learning scenarios to be on par or better than classic learning scenarios. With better knowledge of factors that have a direct impact cognitive processing induction within VR, we can uncover new insights into how to design our virtual environments. VR promises to help create realistic, yet controlled environments which make new research directions possible.

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