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Effects of natural user interfaces on user experience, activation and task performance in immersive virtual learning environments

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Abstract.

The rising digitalization of all life and work areas also rapidly influences higher education. As a driving force of "Industry 4.0" digitalization demands new digital ways of working and new kinds of human-computer interaction. These changed circumstances require new and technical competences of future employees. To prepare students for this, a technologically-oriented teaching and learning process as well as gaining practical experience is crucial. In this context, Virtual Reality (VR) provide new opportunities for practical experience in education, where they can further intensify the students learning experiences to a more immersive and engaging involvement in the learning process. In order to be prepare for the future working life, students have to learn to deal with new technologies. As a first step to use immersive virtual learning environments (VLE) for education and to understand more deeply which kind of experiences students gain while learning in immersive VLE an experimental research study has been carried out. The paper describes the theoretical background of learning in an immersive VLE. Then the user study, which investigates the effect of natural user interfaces on user experience, activation and task performance in an immersive VLE, is outlined. Finally, the results of the user study are presented and discussed.

Keywords: virtual reality, immersive learning, user experience, immersion, virtual learning environment, higher education, individual learning

1 Introduction

The rising digitalization of all life and work areas also rapidly influences higher education. As a driving force of "Industry 4.0" digitalization demands new digital ways

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of working and new kinds of human-computer interaction. This changes the requirements for today's and future employees and students. At the same time, the requirements for the education of those students and thereby for the teaching staff are changing. Apart from "traditional" competences like professional, methodical and social competence especially a confident use of media is demanded from today's graduates [1]. Media didactics are considered a central element in an academic competence profile for the working world 4.0. This means that universities play a key role in educating future employees for a digital working world [1]. The training of digital competences should ideally already start in school, because they also have an increasing importance in higher education teaching. To be able to teach and learn digital competences in higher education new teaching and learning concepts and media are required [1].

Due to the rising number of students, classrooms at German universities are overcrowded and thereby often provide bad learning conditions [2]. Traditional classroom teaching formats are usually unable to meet those difficulties [2], because they don't meet the demands of today's students and future employees of a global digitalized job market. Nowadays, the content-related-didactical design of higher education is shifting from a "one size fits all" teaching and learning approach to a "tailor-made" concept i.e. taking individual aspects such as prior knowledge and the needs and aims of every student into regard [3]. In this context, virtualized teaching and learning formats gain importance. They facilitate a more individualized learning process for students to meet their requirements in higher education.

The use of innovative hardware like the head mounted display (HMD) „Oculus Rift“ opens up new possibilities to teachers and students in the process of teaching and learning. Theoretical knowledge can be transmitted in a more realistic and practice-oriented way during the course of studies by letting the students experience it firsthand. Especially conducting dangerous, expensive or spatially difficult experiments has become possible by the use of these devices. In addition, students can experience the working place of the future since industry 4.0 has not yet been implemented. Furthermore to that, VR can also be used to visualize complex and abstract processes. By its application new ways to an active explorative course of studies open up for students.

In order to fulfill the students' learning requirements, the technical and didactical interaction between immersive hardware and students have to be improved. Therefore, individual factors which influence the students' learning processes in a VLE have to be identified. With the aim of using immersive VLE in education as a teaching and learning tool, the effect of natural user interfaces on the user experience (UX), activation and task performance in a VLE has to be investigated. The paper describes the theoretical background of learning in an immersive VLE. Then the user study to investigate the effect of natural user interfaces on user experience, activation and task performance in an immersive virtual learning environment is outlined. Finally, the results of the user study are presented and discussed.

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2 Immersive virtual learning environments in Education

2.1 Immersive Learning by Virtual Reality

VR is seen as a future technology which gains an increasing importance in industry and research. The progress in this area is driven by the rapid growth of the enhanced performance of hardware and technology, for example new interactive tools and tracking systems [4]. The technological advances and the growing availability of VR facilitate the access to universities because of their easier use and the decreasing costs of HMDs. Hoffmann & Hu [5] define VR as a "highly interactive and dynamic form of simulation in which a computer-generated world or environment can be 'entered', and the three-dimensional (3-D) objects within it 'explored' using visual, aural, and haptic (touching) senses." VR technologies are attributed with an immersive effect, which is initially caused by technological impact. Immersion is the central element of VR, which distinguished VR from other Human-Computer interfaces [4]. One central assumption is that VR technology leads to greater immersion in the VE and in turn higher immersion leads to better learning outcomes [6]. For an increased immersion, the user needs a 3D perspective of the virtual environment which is often realized by the use of HMDs. There are two existing perspectives of immersion: a technical and a user or mental perspective. The technological capability of a VR system to foster immersion implies that the user is surrounded by VR so that barriers between the virtual world and the user disappear. This leads to a greater level of users' attention and focusing [7]. The users' mental experiences in a VR environment are generally summarized by the term 'user experience' (UX), which can further be subdivided into certain theoretical constructs like immersion, presence and flow, which are used in the following. A widespread definition of immersion is from Murray [8], who defines it as a state, in which a user is surrounded by another reality claiming his full attention. Witmer & Singer [6] outline immersion as a "psychological state" and state that the "degree to which they feel immersed in the VE [will increase]" by effectively isolating users from the real world. Furthermore, they assume that a "VE that produces a greater sense of immersion will produce higher levels of presence." Wirth & Hofer [9] share this view. In contrast to this psychological perspective, Slater & Wilbur [10] define immersion as a technical characteristic of VR systems and understand presence as a consequence of an immersive technology. Presence is defined "as the subjective experience of being in one place or environment, even when one is physically situated in another" [6]. In context of VE, presence means the experience of the VE rather than the physical experience [6]. The concept has its origin in technology research at the beginnings of VR in 1970. Presence is the most influenced and researched concept in the field of VE. In contrast to immersion, presence is commonly understood as a user variable and not a technological characteristic. Flow is defined as a reflection-free merging in smooth ongoing activities that have been under control despite high strain [11]. Moreover, someone is in a state of flow, when requirements and competences are balanced [12]. Flow is the most general concept of all three constructs, because the experiences are not limited to media use, but to a series of activities [13]. The concept has its origin in happiness research and was originally used in daily activities [11]. Research studies show that the state of flow has an influence on

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information processing and cognitive load [14]. Considering the state of the art, it can be assumed that technologies which have a greater level of immersion lead to greater UX when users interact with the VE. The question arises to what extent immersion influences task performance in VLE and how immersion can support the learning process in a positive way. Moreno & Mayer [15] state that "[t]he fundamental idea is that students who learn by participating in the learning task with a higher sense of being in the environment may learn more deeply than students who learn by participating in the learning task as observers." Wirth & Höfer [9] add that in particular media with many features that promote presence are being referred to as immersive. The greater the immersion of a medium, the more likely the user experiences presence in the VE [16]. Applying VR in education can further increase the students' learning experience to a more immersive and engaging involvement in learning processes [17]. The immersion into a virtual world offers students the potential to experience virtual objects and to interact with the environment. Thus, a constructivist perspective of the learning process can be encouraged, in which students learn in an active, self-controlled way in situational, problem-oriented contexts. VEs provide a setting that facilitates a more personalized learning process matching students' requirements and offering a higher learning autonomy [18]. To confirm this assumption further empirical evidence is necessary, especially if immersive VLE are to become an appropriate tool for education.

2.2 Hypotheses derived from the literature review

From the literature review and state of the art analysis different hypotheses were derived for the study. The following hypotheses and results are an extract from all tested hypotheses of the study. These extracted hypotheses focus on the effect of natural user interfaces, in this case, the Oculus Rift, on UX, activation and task performance.

Table 1. Overview about the hypothesis

1	Usage of the Oculus Rift leads to a higher presence than usage of the laptop screen.
2	Usage of the Oculus Rift leads to a higher flow than usage of the laptop screen.
3	Usage of the Oculus Rift leads to a higher emotional activation than usage of the laptop screen.
4	Usage of the Oculus Rift leads to a better task performance than usage of the laptop screen.
5	Female persons have a lower task performance than male persons.

3 User Study

3.1 Study Design

To investigate the effect of natural user interfaces on UX, activation and task performance in an immersive VLE, a controlled experiment was developed [19]. The control experiment is set up as an experimental research design. The experimental group use an immersive HMD as the experimental condition. In this study, the Oculus Rift DK 2

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was used, whereas the control group is provided with a laptop screen as the condition. In both conditions, the movement controls in the VLE are equal. In contrast to the laptop screen setup, the Oculus Rift controls the field of view via head movement. The control group using the laptop screen use the W/S keys to go forward and back-ward, while they use A/D keys in order to go left and right in the VLE. Each participant has used either the laptop or the Oculus Rift alone, so that there was no communication between the participants. The process of the experiment is shown in Figure 1.

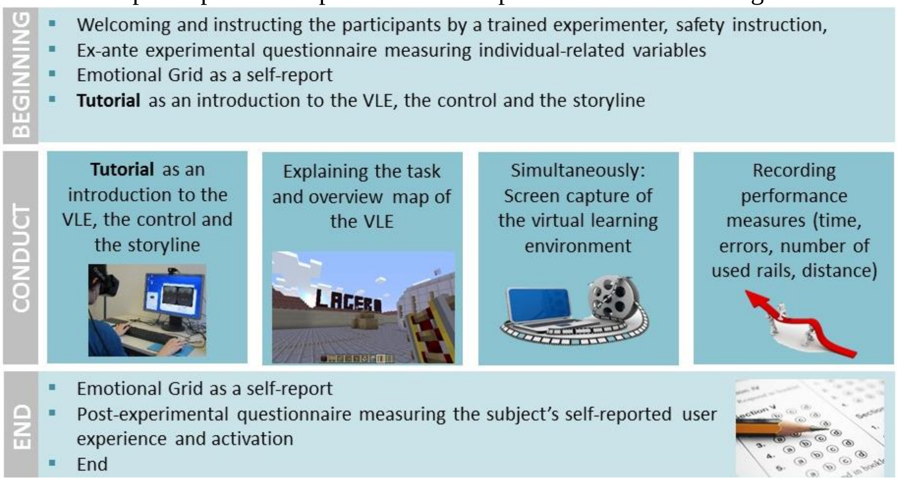

Fig. 1. Procedure of the study

The complete process of the experiment was proved in a pretest with 10 students from university in Germany at an average age of 24,9 years. In the pretest, the procedure, the measuring instrument and the experimental task in Minecraft was tested for didactical, technical and organizational improvements. After the pretest, slight modifications in the experimental task have made.

3.2 Measurements and Variables

To assess the relationship between the immersive capacity of the user interface, UX, activation and task performance in a VLE, a set of independent and dependent variables is defined. As independent variables, the following constructs are under study: Sociodemographic data, like age and gender, Personality traits (10 Item Big Five Inventory), Locus of control when interacting with technology (KUT) [20], Gaming behavior/ frequency of using games, Spatial cognition (Questionnaire Spatial Strategies, QSS) [21], Immersive tendency (Immersive Tendency Questionnaire, ITQ) [6], Immersive capacity of the user interface. All independent variables are collected via self-report information in form of a pre-questionnaire with already existing valid and reliable questionnaires. To measure the gaming behavior, the frequency of playing games as well as the experience with Minecraft and VR Technologies, own questions were constructed following existing questionnaires. The immersive capacity of the user interface comprise the natural user interface, in this case the laptop or the Oculus Rift.

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As dependent variables, three variables are used: UX is measured via the following scales: presence (Presence Questionnaire, PQ) [13], flow (Flow Short Scala, FSC) [22] and game experience (Game Experience Questionnaire, GEQ) [23], Emotional Activation is measured with the affect grid as a self-report, Performance is measured via different parameters: time, number of used rails, errors in form of the number of removed rails as well as the travelled distance and speed of each participant. UX is operationalized by the constructs of presence, flow and game experience. Already existing reliable and valid instruments for those constructs based on subjective reports as a common method to measure UX [18] are used. All items of the pre- and post-questionnaire are answered on a six-point scale, ranging from 1= total agreement to 6= total disagreement. The six-point scale was used in order to avoid answers which are positioned in the middle as with seven-point scales. The methods (self-report and quantitative questionnaires) constitute a complex and detailed description of the conscious and subconscious UX of the students in the VLE.

3.3 Minecraft as the setting for the virtual learning environments

For the experiment, a VLE was developed in the open-world sandbox game Minecraft (see Figure 2). Minecraft is suitable for the use in different academic learning contexts like engineering or geography and for nontechnical learning scenarios like creativity, teamwork or specific skills [24]. Minecraft offers opportunities to explore a VE in a free, active and experimental way to build new objects. Programming capabilities from students or teachers are not required, which allows the application in education due to low cost, time and personal resources needed. Moreover, Minecraft has already been applied successfully in different learning contexts [25].

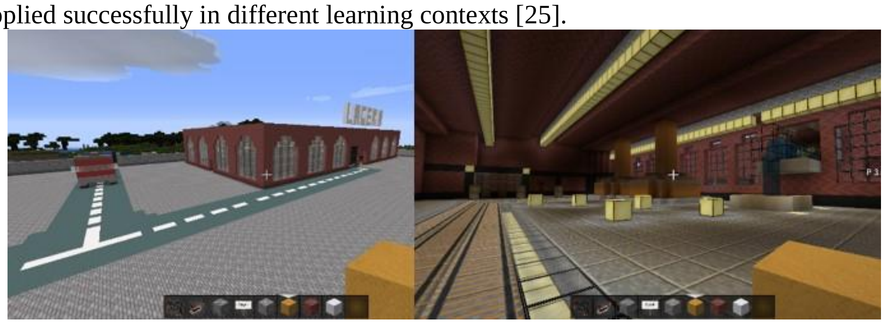

Fig. 2. Virtual learning environment in Minecraft (own image)

In order to use Minecraft as the setting for the VLE, the conception is following the game design steps according to references [26]: define the target group, define learning outcomes of the game, define the game, shape the game idea and elaborate the details (storyline), (technical) implementation of the game. The formulation of learning outcomes is one central aspect for a transparent and effective teaching and learning process. By this, students are empowered to value their decisions, activities and results in the learning process. The following learning outcomes are defined for the VLE: Spatial orientation, Decision Making, Problem solving, Psychomotoric skills.

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3.4 Experimental task

As an experimental task, a problem-solving process has been developed. Problem-solving tasks require a self-employed, active way of finding solutions. The above mentioned learning outcomes for the experimental task, represent the competence which students have acquired after solving the task. In this context, especially, competences in the field of soft skills are addressed. Students have different sub steps to solve the task. First a spatial orientation in the VLE is required. In a next step, a specific way has to be chosen from the students. During solving the task, students have to solve different problems in the VLE. Therefore, the competence of dealing with barriers and problems is trained. Because of that, the experimental task can be used in different teaching and learning domains, like engineering education, geography or communication sciences.
The experimental task is integrated in a storyline in an industrial factory setting where students are employees of a company that produces soft drinks. The students' task is to build a driverless transportation route on rails in order to transport freight from a warehouse to a factory. As requirements to solve the task, participants have to construct the transportation route on rails in an efficient, resource saving and fast way.

Before working on the task, participants have the opportunity to play through a tutorial to get to know the VE and the controls for movement and the field of view. Participants can practice the controls of Minecraft. Participants with the HMD can additionally use the tutorial to familiarize themselves with the HMD and the immersive effect. In order to record the performance parameters, a specifically programmed tool was used. The following task performance parameters were measured: time, number of used rails, errors in form of the number of removed rails and traveled distance of each participant. In addition to that, a screen capturing software (Open Broadcaster Software) is recording the student's movement within the VLE while solving the task. After the experiment, a qualitative interview with a semi-structure interview guide with the participants is conducted to get a deeper insight in the experience of the participants. The results of the experiment are analyzed based on a system of categories which was established through the deductive-inductive approach during the analysis. For the qualitative analysis, the software program MAXQDA 12 was used.

4 Sample and Results

4.1 Sample

56 participants volunteered to take part in the study. 50 % of the participants are students from RWTH Aachen University in Germany and 50 % are German high school students. Students were recruited via social media channels like Facebook and Twitter and via posters on the university campus. The participants received no information about the aim of the study. The only information they were given was that it is about the use of VR technologies in the learning process. Furthermore, the participants were informed about the randomization to the experimental and control group before the start of the study.

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In total, 29,6 % of the participants were female, while 71,4% of the participants were male. The average age of students was 19,56 years (SD = 4,67). The age range varies between 15 and 32 years. The majority of students (50%) have an engineering and scientific background (35,7%), whereas only 14,3 % of the participants study humanities. With regard to the conditions, 48,2 % (n = 27) of the participants had to use the condition with the laptop screen, while 51,6 % (n = 29) of the participants used the Oculus Rift. The gender relation is nearly equal: 50% of the female participants have used the laptop screen and 50 % of them have used the Oculus Rift. 19 (47,5%) of the male participants have used the laptop screen, whereas 21 (52,5%) participants have used the Oculus Rift. The majority of the participants (80,4%) are playing digital games, mostly on their smartphone to an average game time of 10,07 hours per week. In view of the use of VR technologies and Minecraft, 67,9 % of the students have already used Minecraft, whereas only 14,3% of them have used a VR technology before.

4.2 Results

The quantitative data were assessed with a questionnaire with closed questions before and after the study. All quantitative data were analyzed by using IBM SPSS, version 22. All hypotheses were tested with a t-test with an independent sample. The t-test was chosen in order to compare the mean from the two independent sample – experimental and control group. The constructs presence and flow were measured by already existing reliable and valid scales. The task performance were measured by the above listed task performance parameters. Emotional activation was measured by the emotional grid, a self-report measurement which include two bipolar dimension – arousal and affect [29]. The emotional grid was used before and after solving the task.

Hypothesis 1 *Usage of the Oculus Rift leads to a higher presence than usage of the laptop screen* is confirmed. The analysis shows that students using the Oculus Rift have a higher value in the subscale self-localization (M = 4.5, SD = 1.01), t (54) = -3.96, p < .01 and a higher degree of possible action (4.35 (SD = .02), t (54) = -2.75, p < .01 of the scale presence. This means that students using the Oculus Rift have the feeling of being in the immersive virtual environment and more possible actions in it (Figure 3).

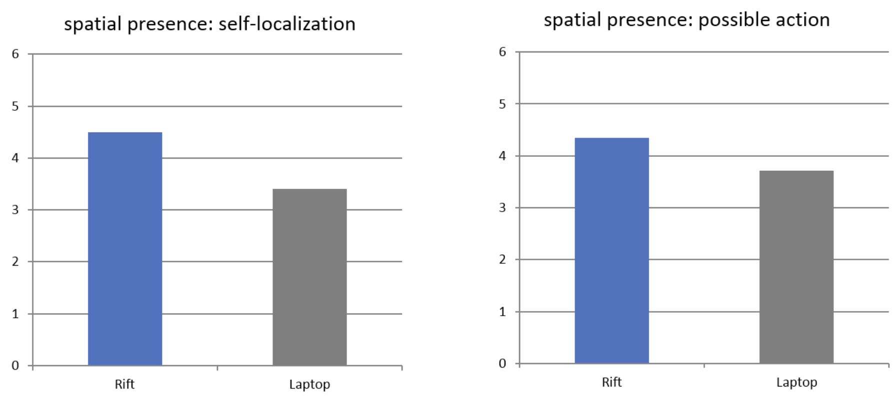

Fig. 3. Presence compared to the user interfaces

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Hypothesis 2 *Usage of the Oculus Rift leads to a higher flow than usage of the laptop screen* is not confirmed. The results show that especially using the Oculus Rift leads to less flow than using the laptop (M= 4.39, SD = .97), t (43,7) = 2.11, p < .05. Particularly obvious is the difference in the subscale "smooth and automatic run". The Oculus Rift User has a value of 4.5 (SD = 1.12) in comparison to 5.27 (SD = .65) of the laptop group, t (45.51). = 3.12, p<.01 (Figure 4). The correlation analysis of flow and the task performance parameters show that the subscale "smooth and automatic run" correlates with the time in the tutorial and the time to solve the task in a negative way. An explanation for the results could be the novelty effect of the technology or that participants with the Oculus Rift have less control of the Oculus Rift.

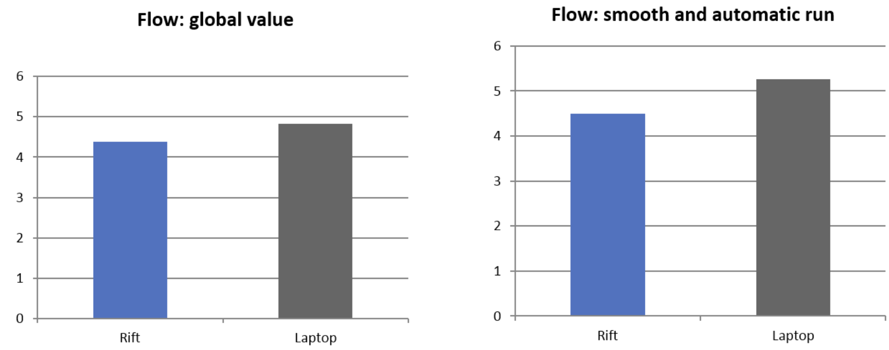

Fig. 4. Flow compared to the user interfaces

Hypothesis 3 *Usage of the Oculus Rift leads to a higher emotional activation than usage of the laptop screen* is not confirmed. Students using the Oculus Rift have reported more negative emotions after the task (M = 5.59, SD = 2.16), t (37.73) = 4.6, p<.00. The difference by comparison before and after the task is also more negative than by the laptop group t (36.93) = 4.53, p<.00. Regarding the activation no significant difference between both groups could be observed (Figure 5).

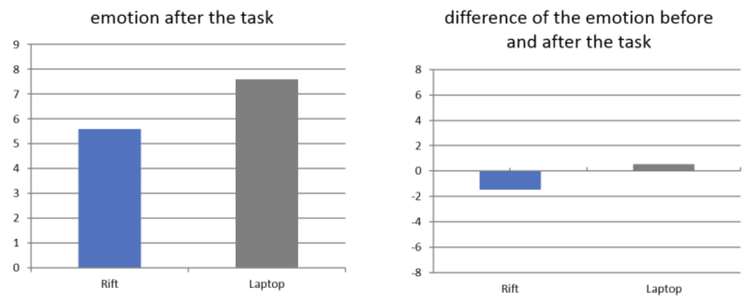

Fig. 5. Emotion compared to the user interfaces

Hypothesis 4 *Usage of the Oculus Rift leads to a better task performance than usage of the laptop screen* can be confirmed only to a limited extent. Students using the Oculus Rift spent 182 seconds (SD = 83,93) more time in the tutorial than the laptop group with 99,65 second (SD = 44.52), t (41,39) = 4.57, p < .00.

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Hypothesis 5 *Female persons have a lower task performance than male persons* is confirmed. Female participants needed more time in the tutorial ($M = 208.88$, $SD = 131.13$) than male participants ($M = 125.35$, $SD = 67.49$), $t(18.27) = 2.42$, $p < .01$. The results of the duration of solving the task are similar. Male Participants solve the task on average shorter ($M= 313.93$, $SD = 179.51$) than the female participants ($M = 554.88$ s, $SD = 226.1$), $t(54) = 4.21$, $p < .00$.

5 Discussion and Future Work

Concerning the effects of natural user interfaces, the results of the user study show that the immersive VLE leads to more spatial presence. Students who used the Oculus Rift report a higher self-localization and more possible actions in the VLE. These results are in line with previous research results which state that an immersive hardware leads to higher spatial presence [e.g. 28]. With regard to flow, there was an opposite effect than initially assumed and which is contradicted to the literature [e.g. 29]. Students who used the Oculus Rift had less flow than students who used the laptop. In particular, students using the Oculus Rift experience less flow in the subscale “smooth and automatic run”. This is might be due to bad hardware. In the study, the oculus Rift development version (DK2) was used which has some hardware problems in comparison to HMD’s which are available for consumer. At the time of the study, there were no HMD’s for consumer available. Another reason for less flow could be that the Oculus Rift has distracted the user. A smooth and automatic run is characterized by focusing and concentration on a specific task. This might be due to general difficulties in handling new technologies and the novelty and unfamiliarity of HMDs as opposed to laptops. Students first have to get familiar with the technology, which takes the attention from the task and therefore they experienced less flow. The assumption that the Oculus Rift leads to a higher emotional activation than the usage of the laptop cannot be confirmed. In contrast, students using the Oculus Rift had more negative emotion after solving the task. Reasons for more negative emotion were identified in the conducted interviews with the participants. Difficulties with the controls, the perception and the properties of the visual presentation of the Oculus Rift were reported from the participants. Likewise, problems with dizziness, nausea and discomfort influenced the emotion in a negative way, which is confirmed through the results of the interviews. Another explanation may be that an intervention that was more focused on affective content would have given significant positive results. The comparison of the task performance parameter shows no significant differences between the experimental and control group except for the time in the tutorial. Students who used the Oculus Rift needed three times longer in the tutorial than the laptop user. The other task performance parameters show no differences between the experimental and control group. These results show that the habituation to new technologies balance differences in the task performance. Using tutorials to get to know the hardware is essential in order to use immersive hardware in the teaching and learning process. Statements of the participants given in the interview confirm these findings. Furthermore, the results in terms of task performance show that both gender as well as VR and Minecraft experiences influences

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the task performance in a VLE. With regard to use VR in education, practitioners has to consider the following recommendations: first the hardware and software must be available and an analysis of the target groups should be made regarding the group size, the topic of the course, the learning outcomes as well as the didactical conception of the course. The analysis of further hypotheses with regard to the effect of personality traits on user experience, activation and task performance is currently still running. Further research is needed in order to investigate which personality traits have a key function in this context. In further analyses, the results of the task performance has to be investigated in terms of their relationship to experience presence and flow in the VLE. A deeper insight on the participants' experiences will allow a more differentiated view on the focus of this research. This helps to get deeper insight into the specific preferences of students in education and their preparation for their future working life. The results serve as an important contribution for using immersive VLEs in learning scenarios in school and universities can be made.

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