The tension between abstract and realistic visualization in VR learning applications for the classroom

Thiemo Leonhardt [1], Lanea Lilienthal [2], David Baberowski [3] and Nadine Bergner [4]

Abstract: While learning applications such as driving simulations aim for the most realistic experience possible, learning in other applications can be hindered by unintentional distractions. Similarly, VR learning applications with a high sense of presence address the learner's attention as well as the emotional component of learning. A high sense of presence can also evoke negative feelings in learners due to the emotional component and thus hinder the learning process. With this tension in mind, this paper analyses two different VR learning applications. The results show no effect of abstract visualization in contrast to realistic, high visualization on user preference and usability between both applications with constant high presence.

Keywords: Visualization, Presence, VR, Learning

1 Introduction

This paper describes the results of an ongoing research effort to develop VR applications for computer science education. Thereby we follow a design-oriented research approach. For VR applications to be used in the classroom, they must be able to be integrated into the flow of a lesson like comparable media. This requires that VR applications are designed for specific learning phases. One of the strengths of interactive simulations, especially in VR, is the representation of and interaction with abstract or even inaccessible places. In the didactics of computer science, it is possible to look into and interact with information technology systems such as computers and routers at different levels of abstraction, to visualize their internal processes and to learn their functionality interactively [De20], [LBB22]. Additionally, visualizations of abstract computer science content like regular automata are realized [De18]. In computer science didactics, conceptual models [GM00] are often implemented using notional machines [Gu19], [MSL21]. In this respect, the visual representation in such learning applications is an

[1] TU Dresden, Professur für Didaktik der Informatik, Nöthnitzer Str. 46, 01187 Dresden, thiemo.leonhardt@tu-dresden.de, https://orcid.org/0000-0003-4725-9776
[2] TU Dresden, Professur für Didaktik der Informatik, Nöthnitzer Str. 46, 01187 Dresden, lanea.lilienthal@tu-dresden.de, https://orcid.org/0000-0002-8508-9483
[3] TU Dresden, Professur für Didaktik der Informatik, Nöthnitzer Str. 46, 01187 Dresden, david.baberowski@tu-dresden.de, https://orcid.org/0000-0001-6308-4334
[4] TU Dresden, Professur für Didaktik der Informatik, Nöthnitzer Str. 46, 01187 Dresden, nadine.bergner@tu-dresden.de, https://orcid.org/0000-0003-3527-3204

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important area of research, since abstract content must be visualized that cannot be measured against real templates.

In this context, the design of VR applications for schools is still an under-researched area. The specific requirements for learning concentration and effective use of learning time need to be questioned and re-evaluated in the context of VR's strengths in motivating learning through immersion, presence, and interaction. To make these strengths of VR learning applications visible for the learning process, the design of the learning applications is of central importance. The extent to which abstract or realistic representations of learning content can influence learning outcomes, and the design decisions that can be derived from this, will be examined in more detail in this paper by comparing two VR learning applications.

2 Theoretical Background

The distinction and definition of immersion and presence is still part of the scientific discourse [BA19]. Slater defines immersion as an objective property of a system [Sl18] Less or more immersion is therefore to be specified as aspects such as display resolution, field of view, sound and similar relevant system components. Definitions of immersion in terms of user engagement or a state of flow [Pl21] should be rejected due to the strong interrelationship with psychological constructs and learning design. The creation of detailed virtual environments as well as the use of 3D models of low detail can certainly influence the effects of the VR learning application on the investigated factors, as an effect on the perception of presence can be expected here. Presence is defined as the impression of being part of the virtual environment [Ma21]. While Plotzky et al. found no scientific consensus on the influence of presence on learning effects [Pl21], they primarily attributed this to the small number of studies available. Learning theories suggest a positive relationship between the sense of presence and learning motivation and effectiveness.

Dengel investigates the relationships and effects between learner-specific variables (presence, motivation, cognition, and emotion), the level of immersion provided and learning outcomes in VR learning applications for teaching computer science [De20]. The model demonstrates an approach in which presence, which was influenced by immersion, cognitive ability, and achievement emotions, predicted learning outcomes along with the correlated factors of contextual motivation and cognitive ability, both of which also influenced learners' achievement emotions. While there was evidence that higher immersion was associated with higher learning outcomes, significant predictive effects were found between presence and learning outcomes.

Radianti et. al. [Ra20] found in a systematic mapping study that immersive VR technologies are considered a promising learning tool in higher education. However, most of the technologies described in the reviewed articles were still at an experimental stage, mainly tested for performance and usability. Similarly, only a few papers described in detail how VR-based instruction can be integrated into higher education curricula. Similar research on the use of VR in schools is scarce. Zender et al. [Ze22] argue that many questions regarding learning effectiveness, pedagogical and didactic design, as well as medical and ethical risks of use cannot yet be adequately answered for schools. Previous design specifications for VR learning applications do not specifically address the needs of schools. As part of his Multimedia Design Principles, Mayer formulates the *Immersion Principle*, which states that immersion does not necessarily improve learning, but that effective teaching methods in immersive virtual environments can improve learning, based on 35 studies from 2018 to 2021 [Ma21]. The main theoretical implication of the immersion principle in multimedia learning is that teaching methods can be used with immersive media to promote better learning. Research that has addressed the implications of instructional design in immersive learning environments is very limited. VR learning applications in particular show good results in teaching declarative and procedural knowledge [Ra20], [LBB22].

3 Applications Design

The *Inside the System* series, developed at the chair of Didactics of Computer Science at TU-Dresden, aims at the possibility to get inside computer systems and to understand and control their internal processes. Thus, the training of procedural knowledge about the internal processes of computer systems is built. To fit into a regular school lesson, the games were designed to have an average playing time of maximum 10 minutes. The implementation in VR assumes a higher motivation and activity of the learner and thus to produce good learning results. To compare the effect of abstract and realistic visualizations of VR learning applications, the two VR learning applications *Inside the Router* (ITR) and *Inside the CPU* (ITC) were designed differently.

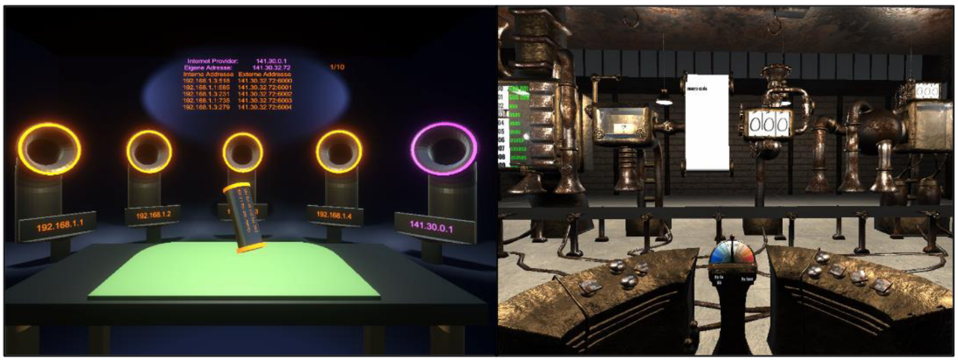

Fig. 1: First person views of *Inside the Router* (left) and *Inside the CPU* (right)

In ITR, the three main cases for routing IP packets in a home router that relate to everyday use cases are internal packets, outgoing packets, and incoming external packets. To practice an abstract task like routing, a metaphor is needed to haptically grasp the task. For Inside the Router, this metaphor is a pneumatic tube system in which the routes to the various network components are pipes. The IP packets are symbolized by capsules transported by these pipes. The main interaction as part of the game mechanics are the three steps: Catch, Decide, Throw. The didactic reduction following the German educational standards of CS for Inside the Router is described in detail in [LBB22]. The design of ITR follows an abstract visualization but high presence approach. Detailed representations of the pipes and packages were omitted and at the same time the virtual room was darkened so that the learner's attention is focused on the components relevant for learning. Thus, instead of implementing a detailed, more realistic representation of the visual component (electronic circuits and components), an abstract space was created. However, in order not to reduce the sense of presence at the same time, the learner is placed in the center of the room and all interactions are continuously performed by the learner. The darkened room should at the same time give the learners the feeling of being in an abstract space, which is only defined by the activity of sorting.

ITC places the user in an abstraction of a computer system, the Von-Neumann architecture of a computer. The player controls a machine made up of five components that relate to the components of the Von-Neumann model. As in the model, the machine’s task is described by macrocode instructions in the RAM. The player retrieves these instructions and executes the corresponding microcode using control elements such as buttons and levers from a central console. The didactic reduction is equivalent to other widely accepted simulations for this topic in German secondary school CS education, such as Jhonny[5]. The steampunk-oriented design of ITC aims for a more realistic visualization and a high presence. The former is achieved by using highly detailed textures and complex 3D models for the main interactable objects. In contrast to ITR the background is also visible and uses detailed textures and factory ambient sounds. High presence is achieved by not using the input buttons of the VR controller, but by having the user grab and move the control elements on the central console. The components of the Von-Neumann machine are realistically animated and underlaid with sound effects which contribute to both immersion and presence, by linking the high detailed environment to user interactions. As in ITR the user is placed in the center of the room with all controls within reach, but in contrast to ITR the machine’s components and surroundings are well illuminated and perceived in detail.

4 Comparative Analysis

Characteristics regarding VR of the application are considered in factors *immersion, presence,* and *interactivity*. The applications were tested with current high-end VR systems (HTC Vive Pro Eye, PICO 3 Pro) to compare the results. Accordingly, differences in immersion can only be attributed to the in-game representations. We use the Virtual

[5] https://sourceforge.net/projects/johnnysimulator/

Reality Learning Performance Model [LBB22] to measure the performance of the applications. The study was conducted with prospective teachers of computer science in their first semester. The two applications were tested separately with different subjects (ITR N=28; ITC N=13).

	ITC (N=13)		**ITR (N=28)**	
General Presence (IPQ)	M=4.86	SD=1.834	M=5.21	SD=.791
Spatial Presence	M=4.843	SD=1.216	M=5.36	SD=.791
Involvement	M=4.054	SD=1.190	M=4.47	SD=1.163
Experienced Realism	M=2.750	SD=.519	M=3.179	SD=1.128
Interactivity (IS)	M=1.476	SD=.566	M=1.571	SD=.753

Tab. 1: Mean (M) and standard deviation (SD) of both applications.

The IPQ (igroup presence questionnaire) to measure presence consists of 13 items on a scale between 1 to 6. 12 of the items are divided into 3 subscales (Spatial Presence 5 items, Involvement 4 items, and Experienced Realism 3 items). The last item (G1) loads on all three factors and simultaneously represents the General Presence factor. The Interactivity Scale (IS) consists of 3 Items on a scale between 1 and 7 where 1 corresponds to high interactivity. Accordingly, the VR-specific observation showed a strong sense of participant presence (high IPQ) and a high sense of interactivity regarding the IS scale analysis for both applications (see table 1). As the applications show the high levels of presence and interactivity expected from the design, a possible influence of realistic or abstract representations in the visual presentation on user preference and learning performance can now be measured. User preference can be surveyed via user experience (UEQ-S), usability (SUS) and VR specific motion sickness (MSAQ). Learning performance is investigated by considering flow experience in the learning process (FSS).

To measure the two independent samples, the non-parametric Mann-Whitney U-test for independent samples was performed on all scales and subscales. All requirements for the test[6] are met. No significant differences were found between the two applications on any of the scales (user experience, usability, VR specific motion sickness), so the null hypothesis of no difference in user preference and learning performance between ITR and ITC is maintained. The beta error was calculated to test the null hypothesis. No effect of abstract visualization in contrast to realistic, high visualization on user preference ($1-\beta=.99$) and usability ($1-\beta=.92$) with constant high presence could be demonstrated. For the MSAQ ($1-\beta = .07$) and the Flow ($1-\beta=.12$) the power is not sufficient to make a valid statement about the null hypothesis. To measure actual learning effects beyond the flow experience, the learning content must be comparable, therefore an abstract visualization version of the ITC application will be implemented in a follow-up study.

[6] Independence of measurements, independent variable is nominally scaled and has two expressions, dependent variable is at least ordinally scaled and distribution form of the two groups is approximately equal.

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