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IT’S TOOL TIME: EXPLORING TOOL REPRESENTATION ALTERNATIVES FOR VIRTUAL REALITY TRAINING

Research Paper

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Abstract

Virtual reality (VR) technologies have gained a steady increase in attention and use in organizations across various industries in recent years. A useful application scenario is VR training, enabling employees to immersively and interactively familiarize with or practice work processes in a safe space without the risk of physical harm or financial consequences for the organization. This research explores how tool representation alternatives in virtual reality training scenarios (VRTS) affect user experience and content transfer. In a two-stage research approach, a total of 20 participants are randomly assigned to one of two VRTS with different tool representation types and interviewed subsequently. The findings indicate that decisions regarding tool representation in VRTS should be based on tool-independent (e.g., the feeling of tool operation) and tool-dependent factors (e.g., tool complexity).

Keywords: Virtual Reality Training, Tool Representation, Content Transfer, SME.

1 Introduction

The application and use of immersive virtual reality (VR) technologies is due to its experienceable and interactive character a promising response to organizational challenges that deal with the transfer of work practices (Bellalouna, 2020). In addition, the use of virtual reality (VR) indicated a positive impact on employee motivation (Pöhler and Teuteberg, 2021). Employees can familiarize with work processes in a safe space and the risk of physical harm and financial consequences through material and time savings are reduced for the organization (Schwarz et al., 2020).

Nevertheless, the development and design of virtual reality training scenarios (VRTS) involve high effort for organizations, the richer the features they contain. These are related to a high level of programming effort involved in adapting the VR environment to practicable application scenarios. In addition, VR design approaches have not been widely standardized to date, which also results in high time and work efforts (Liagkou et al., 2019). Furthermore, there is a lack of availability of high-quality 3D models on the web, but even if they were available, integrating and adapting them to VR still requires a lot of work (Downs et al., 2022). Scanning objects with 3D scanners is also not a viable solution. On the one hand, high-quality 3D scanners are particularly expensive and, on the other hand, the 3D scans created have to be laboriously post-processed and converted into the appropriate format in order to be able to use them in the VR environment (Jadhav et al., 2019). Especially for small and medium sized enterprises (SME), the effort associated with the development of immersive VRTS continue to be a barrier due to limited resources (Schwarz et al., 2020).

Fortunately, the VR environment and its objects can be represented in different levels of detail (Tian et al., 2021). Nevertheless, when deciding on the representation level for VRTS, the organizational use-case and the aim of the VRTS should be taken into account (Yildiz et al., 2019). VRTS consist for instance of mapping technical work processes in which different tools are used (e.g., maintenance or assembly processes) (Bellalouna, 2020). Tools include all usable objects that allow the VR user to interact with and manipulate the VR environment and therefore enable the successful execution of work steps. The tool representation can thus simultaneously shape the users' interaction with the virtual environment. The representation of tools in VR is initially based on their nature and interaction in reality. Since VR tools offer a wide range of representation alternatives, their development can be associated with an increased workload and development effort. In this research, tool representation includes the tool dimensionality (2D, 3D) and the enrichment with appropriate feedback (auditive, visual, haptic). The comparison of 2D and 3D tool representation is based on the fact that, in contrast to the described effort of integrating 3D objects, 2D integration requires comparatively small effort. For 2D integration, an image file of the tool is sufficient.

Huchler et al. (2022) emphasize that a correct tool operation and execution can be poorly represented in VRTS while work processes are good to convey (Huchler et al., 2022). If tool operation cannot be adequately conveyed by VR the question arises, whether tool representation trade-offs have the potential to reduce development effort of VRTS. Nevertheless, tools form a major part of the interaction in VRTS and are indispensable for the workflow and the design of the work steps. The aim of mapping tools in VR is to provide the user with a virtual training situation based on real world work processes. Tool representation in VR does not aim to teach tool operation, but to create an understanding of their use in the right place at the right time. For sustainable use and enjoyment of VRTS neither the user experience should suffer nor the content to be transferred should be misunderstood (Schwarz et al., 2020). VRTS serve to convey work processes and process-relevant information (Bellalouna, 2020). For this purpose, this research investigates how different tool representation alternatives are related to user experience and content transfer. The user experience in this research specifically refers to the user's interaction with the different tools and their representation. Content transfer is about the extent to which the user perceives and understands the depicted work process displayed in the VR.

This research is driven by a practical interest in supporting VR developers and designers in weighing tool representation alternatives for VRTS, with particular attention to the development effort, by deciding in consideration of the user experience and the intended content transfer. The focus of this research is on what potential trade-offs can be made in tool representation in VR trainings to make them more accessible to SMEs by reducing development effort. Therefore, this research was embedded in a specific practical context, namely the crane assembly of industrial crane systems. In the virtual assembly, tools are required to be able to successfully perform the assembly steps. Against this background, this work addresses the following research question (RQ):

RQ: *How does tool representation relate to content transfer and user experience in VRTS?*

To answer the RQ this work is structured as follows: First, the theoretical foundation is outlined. Second, the research approach is presented. Third, the findings are described systematically. Fourth, the findings are discussed and implications for theory and practice are derived. Finally, the limitations of this research are highlighted and an outlook on future research is given.

2 Theoretical Foundation

This research aims to investigate tool representation alternatives in VRTS. Specifically, 2D and 3D representations of three different tools are compared that are enriched with different feedback types (auditive, visual, haptic). The VR environment is identical and 3D in both scenarios. It represents three work steps of an assembly process in which the tools are used to interact and manipulate the environment. By interacting and operating the tools, the user can execute and complete the corresponding work steps. VRTS are used to teach work processes and thus selected content, taking advantage of the potential of virtuality and work on the object (Pöhler and Teuteberg, 2021). The content and work steps must be mapped in a way that they are comprehensible to the user and that the VR use takes on a motivating character (Schwarz et al., 2020). Against this background, this research is embedded in existing research on feedback and interaction design in VR, object representation in virtual environments, and Virtual reality training scenarios.

2.1 Feedback and Interaction Design in VR

As for all interactive systems, a large body of design guidelines, principles, heuristics, and best practices exists for VR applications. In recent years, these have been continuously expanded and adapted driven by new application scenarios that place new demands on the technology and the interaction with it (Krauß et al., 2021). The design of VR applications poses new challenges, but also potentials. Particularly, the use of head mounted displays (HMD) enables a different kind of interaction and thus offers room for new user experience guidelines with regard to the design (Vi et al., 2019). In addition, auditive, visual, and haptic feedback can be integrated to support content transfer within VR and increased the overall user engagement (Allcoat and von Mühlenen, 2018). The challenge in enriching VR content with different feedback types is that it needs to be actively coordinated. This means that the enrichment has to be implemented in a way that the user can perceive different types of feedback from one source at the same time (Sikström et al., 2016; Gibbs et al., 2022). Human perception occurs primarily through vision. For this reason, visual feedback is particularly relevant to VR design and can take different shapes: text- or image-based data can be displayed, visual effects as the (dis-)appearance of the content as a result of user-based actions, or a change of state by the user such as lights turning on and off. Zhang et al. (2005) show that visual and auditive feedback supported assembly work. The participants found the combination of both types of feedback most helpful (Zhang et al., 2005). Auditory feedback includes all sounds and signals that auditively enrich the VR experience. It encompasses spoken instructions for the VR scenario, signal tones for the successful completion of a task, the sounds made by a tool, or even incidental environmental sounds (Sikström et al., 2016). Haptic feedback appears as a response to the interaction with a system. Common VR controllers (here: HTC Vive Pro 2.0) provide haptic feedback through vibration (Muender et al., 2022). Haptic feedback is used to make the VR experience more realistic (Gibbs et al., 2022). Muender et al. (2022) divide their haptic fidelity framework into three areas (sensing, hardware, and software) and show that haptic feedback not only refers to the controller’s vibrations but also to the user’s handling experience when holding the controller. These include the surface structure, the size, and also the controller’s weight (Gibbs et al., 2022).

Frequently, VR interaction design pursues the objective of making interactions as natural and realistic as possible to increase user performance and usability (Bowman et al., 2012). McMahan et al. (2012) investigated to what extent less natural interactions (semi-natural) or even interactions that are not natural at all (non-natural) in VR affect user performance and usability. They developed the “Framework for Interaction Fidelity (FIFA), which can be used to assess the degree of interaction fidelity provided by a technique compared to a real-world action” (McMahan et al., 2016, p. 59). Interaction fidelity is “the objective degree of exactness with which real world actions are reproduced in an interactive system” (McMahan et al., 2016, p. 59). McMahan et al. (2016) gained insights into FIFA application in different case studies: First, they showed that high interaction fidelity is generally associated with high usability and increased user performance. Second, however, low interaction fidelity performed better overall than mid interaction fidelity. According to this, the relationship between interaction fidelity and usability, and user performance follows an U-shaped pattern. They mention familiarity with known real-actions and interfaces as a possible reason for this. Nevertheless, VR experiences with mid interaction fidelity correspond to reality in many cases, as developers have to make allowances for limited technical and financial resources. McMahan et al. (2016) therefore suggest that VR designers and developers should draw on natural actions from reality and familiar user interfaces from other computer interfaces for the design of interaction within VR to leverage the user experience of familiarity.

2.2 Object Representation in Virtual Environments

In virtual environments objects can be represented in 2D or 3D (Tian et al., 2021). Research has shown that hybrid designs are suitable not only in terms of cost-benefit (Kraus et al., 2020) but also for broader context- and task-dependent purposes (Hepperle et al., 2019). In some cases, 2D designs proved to provide a better overview, while 3D designs were more fun and encouraging to use. Furthermore, for easy-to-learn content, visualization in 2D led to better results, while for overall comprehension, a combination of 2D and 3D representations performed better (Hepperle et al., 2019). However, this research was related to the design of a VR interface. Overall, previous research is predominantly not related to the comparison of 2D and 3D representations within VR but to the comparison of 3D VR with 2D desktop visualization in different contexts e.g., gaming (Roettl and Terlutter, 2018), learning (Fussan and Hanesova, 2020; Greuter et al., 2021; Johnson-Glenberg et al., 2021), and rehabilitation (Slobounov et al., 2015; Lledó et al., 2016; Bilgin et al., 2019). Several findings emerge from these comparisons, although their transferability to representation alternatives within VR cannot be certainly assumed: Reottl and Terlutter (2018) demonstrated that representations in 3D VR led to a higher cognitive load on the user by providing a higher level of presence and increased depth perception. This in turn led to faster eye exhaustion and dizziness. Furthermore, users did not evaluate the video game as less attractive than the 3D or VR version (Roettl and Terlutter, 2018). In the context of learning, Fussan and Hanesova (2020) determined that the transfer of learning content with the help of 3D VR turned out better than the transfer through 2D representations. According to the authors, the results are not representative, as learning success was measured by final grade statistics and the results were influenced by the users' prior VR experience, as this had a significant impact on how much learners could focus on the VR content (Fussan and Hanesova, 2020). Greuter et al. (2021) investigated whether students could detect aneurysms faster using 3D VR than 2D image desktop representations and found that the time to detection was shorter in the 3D VR representation. The 3D representation in VR significantly supported spatial orientation and perception, making it easier for the students to recognize the aneurysm (Greuter et al., 2021). Johnson-Glenberg (2021) investigated whether the learning effect within a 3D VR is more pronounced than with a 2D desktop representation. The results showed that the 3D VR produced better learning outcomes through embodiment, presence, and engagement. They attributed the low learning outcomes in the 2D representation to a lack of interaction with the content and low actionability. Users' expectations of being able to interact with the content were disappointed, which negatively impacted learning success (Johnson-Glenberg et al., 2021). In the rehabilitation context, Bilgin et al. (2019) investigated the differences in the effect of 2D desktop representations and immersive 3D VR representations on emotional arousal and relaxation. They were able to demonstrate a greater effect on emotions by the immersive 3D VR application (Bilgin et al., 2019). Slobounov et al. (2015) investigated the effects of immersive 3D VR representations and less immersive 2D VR environments on brain function and behaviour. They found that immersive 3D representations induced a higher sense of presence and users exhibited better spatial navigation. Overall, immersive 3D VR required increased sensory and brain resources for cognitive and motor control (Slobounov et al., 2015).

The focus of prior research has been on either comparing 2D desktop visualizations versus immersive 3D VR visualizations. There is limited research directly comparing design alternatives (2D vs. 3D) within immersive VR. In addition, existing comparisons likewise refer to the richness of the entire VR environment design rather than the design of individual objects. While existing research shows similar trends such as better spatial orientation, higher cognitive load, a higher sense of presence, and higher learning success for knowledge that can be gained through interaction and manipulation of the content in immersive 3D VR, these show different trends in their expression in different application domains.

2.3 VR Training Scenarios

The application and use of VRTS in various domains has become widespread in recent years due to their "unique potential to foster human cognitive functions (that is, the ability to acquire and process information, focus attention, and perform tasks)" (Torro et al., 2021, p. 48-49). The opportunity to experience a wide variety of work processes in a particularly immersive and interactive way, independent of space and time, is of interest to organizations in a wide range of fields (Torro et al., 2021). Employees can familiarize with work processes in a realistic and interactive way in a safe space, carry out initial work steps, experience dangerous situations, and thus prepare themselves for real-life practice and gain self-confidence (Xie et al., 2021). In this way, familiarization times can be reduced in the best case and there is no material wear on the organizational side (Schwarz et al., 2020; de Freitas et al., 2022). In addition, the use of VRTS has a lightweight gaming character, which makes the experience interesting and offers a motivating and valuable digital experience away from daily work routines. If VRTS offer a multi-user mode, there is the possibility of virtual social interaction and collaboration, which supports knowledge transfer and collaboration (Weigel, Sauter, et al., 2021; Weigel, Zeuge, et al., 2021). Nevertheless, although VRTS have become more affordable over the years, SMEs still face challenges as the lack of internal competencies to successfully set up a VR and integrate it into existing work processes. In addition, VR content must be developed specifically for the organization's requirements and at a low level so that the use of VRTS is economical (Bellalouna, 2020).

However, opinions differ on the design of VRTS. Although they all pursue similar goals, namely to guide the user through the VRTS in a user-friendly, motivating way and to make the content transfer as successful as possible, the design recommendations differ. This may be related, among other things, to the fact that different goals are pursued, where the underlying real-world work practices vary in richness and complexity, and the intended content transfer differs. VRTS developed so far contained in many cases fixed task sequences. That means, at the same time, there is little or no room for the user to solve tasks in different ways or to try out their own solution ideas (Schwarz et al., 2020; Heinlein et al., 2021). The acquisition of skills and experiential knowledge in fixed predefined VR scenarios is restricted or not possible at all (Ragan et al., 2015; Xie et al., 2021). For design, this means that the focus seems to be on the content of the VRTS and how it motivates, engages, and thus delivers an overall user-friendly VR experience while familiarizing the user with work processes (de Oliveira et al., 2020; Torro et al., 2021; Huchler et al., 2022).

3 Research Approach

This research followed an explorative qualitative approach since the aim was to investigate tool representation alternatives and their impact on the user experience and the content transfer in VRTS. To answer the RQ (*“How does tool representation relate to content transfer and user experience in VRTS?”*) a two-step methodological approach with a total of 20 participants was applied. All participants first undergo one of two VRTS in which exclusively the tools and their associated feedback were designed differently (c.f., Table 1). Each participant was recorded via screen recording during the VR use. Afterwards, a semi-structured interview was conducted. The interviews started by reviewing and reflecting the recording. This two-stage approach was chosen to address a known shortcoming of interviews: When the interview is conducted separately from the application being tested, participants have difficulty recalling perceptions, specific content, and experience with the system. Thus, when participants talk about the experience or their perceptions, they talk about what they can remember. The interview took place immediately after the VR experience so the time gap between the VR use and the interview was as small as possible. This was to ensure that the VR use is as present as possible in the participants' minds to obtain interview data that is as close as possible to what they experienced (Lazar et al., 2017). Additionally, the recording allowed to reflect on the VR use and to connect the actual behaviour and the user’s perception during data analysis (Miller and Crabtree, 1999).

3.1 Experimental Set-up

First, the participants are introduced to the VRTS in terms of content and technology. Then, the method of between-subjects design is followed (Charness et al., 2012). 10 participants go through VRTS 1 and the other 10 participants go through VRTS 2 both depicting three successive work steps of a crane assembly: measuring the edge distance (1), drill a test hole (2), and unpack the crane parts (3). For the work steps mentioned a laser distance meter (1), a drill (2), and a cutter knife (3) are required. The three work steps represent realistic sub-steps of a real crane assembly work process, follow a specific goal, and have to be executed in a predefined order. The two VRTS differ in the tool representation (c.f., Table 1 and Figure 1). In scenario 1, the tools are embedded in 3D, while in scenario 2 the tools are embedded in 2D .png files.

Figure 1. Tool representation 2D (top) vs. 3D (below).

Within scenario 1 the user receives visual, auditive, and haptic feedback. In scenario 2 the user receives visual feedback (c.f., Table 1). Both scenarios are similar immersive 3D VR environments ensuring that the user's focus is on the tool representation and its associated feedback. The VR user perceives the VR environment through the eyes of an avatar and the controllers are represented by the abstraction of human hands. The three steps took an average of eight minutes to complete.

Scenario – Tool representation	Work step	Feedback	Feedback description
1 - 3D	(1)	visual	market spot on the floor
			dynamic target on the wall
			laser beam on the target during execution
			target on the wall disappears when the task is successfully done
		auditive	sound when the task is successfully completed
		haptic	slight vibration during the measuring process
	(2)	visual	market spot on the floor
			snap-in function between drill and hole
			drilling depth is displayed dynamically
			dust formation during drilling
			spot on the floor disappears when task is successfully done
		auditive	drilling sounds
			sound when the task is successfully completed
		haptic	strong vibration during drilling
	(3)	visual	marking on the packaging
			package disappears when task is successfully done
		auditive	cutting sounds
			sound when task is successfully completed
		haptic	slight vibration when cutting the package
2 - 2D	(1)	visual	market spot on the floor
			static target on the wall
			UI appears when task is successfully completed
	(2)	visual	market spot on the floor
			hole appears when task is successfully completed
	(3)	visual	package disappears when task is successfully completed

Table 1. VR work steps with associated feedback.

3.2 Interview Design

Participants were interviewed based on a semi-structured interview guideline with open-ended questions. The interviews lasted an average about 16 minutes. They were recorded to transcribe and analyse them later. Semi-structured interviews are particularly well suited to obtaining the richest possible responses and, if necessary, being able to elaborate on them by responding flexibly to participants' answers. To avoid typical pitfalls of qualitative semi-structured interviews, Sarker's guide for qualitative research was followed (Sarker et al., 2013). Thus, the first version of the interview guide was evaluated based on two VR sessions (scenario 1 and 2) and two pilot interviews. On this basis, minor adjustments could be made to the interview guideline, through which the questions were again specified. In addition, the recording of the participant's VR view during the VR use was taken as a basis to reflect the work steps and to make the experienced repeatedly present. The interview guideline is divided into four categories: 1) introductory questions about age, profession, position, and VR experience; 2) control questions on content and understanding of the VRTS; 3) questions on content transfer through the VRTS; and 4) on tool use perception and feedback. Categories 2 - 4 were developed based on the theoretical foundations on interaction and feedback in VR, VRTS and the representation of objects in VR. Category 2 includes 5 questions, category 3 includes a total of 9 questions, and category 4 includes 8 questions. Sample questions from category 2 include *"Please briefly describe in your own words what you just experienced."* and *"In your estimation, what is the aim of the VR scenario?"*. For the content transfer from category 3, for instance, the questions *"Which tools did you use for the individual work steps?"* and *"To what extent were you able to determine whether you performed the work steps correctly?"*. To examine perception and feedback of the mapped content, questions in category 4 include questions like, *"How did you perceive control over the tools during use?"* and *"Please describe differences in your use of the three tools."* posed. Following the pilot interviews, a total of five interview questions were supplemented. For instance, the added question *"Where would you place the performed work steps in the overall assembly process?"* allowed a deeper insight into the understanding of the VR scenario context. In addition, the questions *"Did you get the feeling that the tool followed your natural movements?"* and *"Did you already know the tools from reality, or have you already used them?"* provided a deeper insight into the perception of tool use and the context of prior knowledge.

3.3 Participant Selection

In total, data was collected from 20 participants with a variety of professional backgrounds. This aims to ensure that both participants with different prior technical knowledge and existing or missing reference to crane assembly were considered. To obtain the most diverse perspectives possible, German participants were selected from a variety of professional backgrounds. Participants were randomly assigned to the groups (scenario 1 vs. scenario 2). Overall, 65% of participants were male and 35% were female. The average age was 29,6 (SD = 9,4) and participants had an average of 4 times of VR experience (c.f., Table 2). Times defines the number of times an immersive VR application was used.

Scenario – Tool Representation	**Participant**	**Gender**	**Age (years)**	**Profession**	**VR Experience (times)**
1 - 3D	1 - 1	f	22	Finance	0
	1 - 2	f	29	Product Management	0
	1 - 3	m	26	Controlling	1
	1 - 4	m	27	Engineering	0
	1 - 5	f	30	Sales	0
	1 - 6	m	28	Marketing	0
	1 - 7	f	27	Sales	0
	1 - 8	m	30	IT Administration	16
	1 - 9	m	31	Order Management	4
	1 - 10	m	28	Human Resources	5

2 - 2D	2 - 1	f	22	Student	0
	2 - 2	m	28	Research	20
	2 - 3	m	26	Research	0
	2 - 4	m	57	Engineering	1
	2 - 5	f	53	Administration	0
	2 - 6	m	23	Student	0
	2 - 7	f	23	Student	0
	2 - 8	m	20	IT Administration	25
	2 - 9	m	34	IT Administration	6
	2 - 10	m	27	Purchases	5

Table 2. Participant overview.

3.4 Data Analysis

After the interviews were conducted and transcribed they were analysed using MAXQDA software. Therefore, Grounded Theory methods were used (Corbin and Strauss, 2014). In the first step, open coding was applied to break the interview data into specific parts (*e.g., ‘status of workstep unclear’, ‘perceived tool dimension’, ‘sequence of tasks’*). In the second step, axial coding was used to draw connections between the specific parts and organize them into categories (*e.g., ‘status of work steps’, ‘content understanding’, ‘tool handling’*). In the last step, the categories were brought together with four overarching categories (‘*tool-dependent factors’, ‘tool-independent factors’, ‘tool complexity’, and ‘tool familiarity’*) by following selective coding. These represent the core categories for answering the RQ. The coding procedure is explained by an example code path: Participants of both scenarios explained how they recognized the status of work steps within VR or what information they missed in this regard:

“So, with the laser I got a distance on the display, so that was done for me.” (Interviewee 1 - 4)

“With the laser, however, [...] I would have expected that from the point where I measure the distance to the wall, that a laser is somehow displayed to me, which somehow shows the distance [...] or that I get certain feedback that I am measuring the distance.” (Interviewee 2 – 2)

Scenario 1 and 2 included work steps the participants could recognize the status based on the VR representation but also work steps they could not. Here, the codes '*status of work steps unclear*' were created for interview excerpt 2-2 and '*end of the work step clear*' for interview excerpt 1-4 (open coding). These codes were combined scenario specific into the code '*status of work steps*' (axial coding). Along with the axial codes '*tool-handling*' and '*successful task execution*', these codes were combined in the code 'tool-independent factors' (selective coding).

4 Findings

The findings are grouped in ***tool-independent factors*** and ***tool-dependent factors***. The ***tool-independent factors*** include the feeling of tool operation (on/off), the feeling of actually having the tool in hand, the start and completion of the task to be performed with the tool, and the feedback on the successful execution of the task (right/wrong). Tool-operation and tool-handling are tool-independent factors, since tool-operation is not about the concrete operation of the tool and tool-handling is not about the concrete handling experience. Tool-operation is about whether the operation can be perceived by the user, while tool-handling is about the visualization of the tool in the context of the user's virtual hand. In scenario 2, all participants stated they did not perceive the actual ***tool operation***. Thus, they did not feel they were operating a tool and therefore actively performing the work step. They predominantly stated they lacked understanding of the task as a result. In contrast, in scenario 1 they were able to perceive the tool operation through the feedback during tool use. For instance, they saw that the target filled up when they operated the laser and that dust was created when they drilled.

“Yes, the laser, for instance, also emitted a laser beam when it was used, the drill moved and dust was stirred up. Therefore, it was relatively easy to see that the tools were operating.” (Interviewee 1 – 6)

“Otherwise, I expected a bit more feedback. So that you just know it worked now.” (Interviewee 2 – 9)

Additionally, participants repeatedly described the feeling of ***tool handling***. Participants of scenario 1 stated they had a good sense of tool control because the tools were visualized in their hand. They indicated that this gave them the embodied feeling of really having the tool in their hand. The tools also follow their natural movements (e.g., tilt and rotation). Participants in scenario 2, in turn, explained that the schematic representation of the tool did not make them feel that it was a part of them. The handling experience was thus not real, which led them to describe it as unintuitive. They also stated the tool did not follow their natural movements and seemed rather static. This also had an impact on their own movements, which also became static.

“But I already had the feeling that I really had the tools in my hand.” (Interviewee 1 – 10)

“Using the tools feels like you're really doing it. It's not very abstract I would say.” (Interviewee 1 – 8)

“I just lacked direct contact with the tool. There is no feeling.” (Interviewee 2 – 4)

“So that's just difficult because you don't have to make the normal movements. You saw the tool in front of your hand, but the problem was you didn't really have it in your hand.” (Interviewee 2 - 2)

A decisive difference between the two scenarios was revealed in the participants' perception of the ***start and completion of the work steps***. While in scenario 1 participants easily recognized the status through the feedback types, in scenario 2 they perceive the status inadequately. In scenario 2, the participants perceived only the unpacked crane parts as a completed work step, since this was clearly recognizable by the visual feedback. Understanding about the start and end of a work step gave the participants an aid to orientation. In scenario 2, this orientation was missing, which ultimately led to the participants being confused.

“When cutting, a line was marked where I could orientate on. Or, for instance, when I was measuring, the green circle was running. I was able to orientate a bit on that.” (Interviewee 1 – 1)

“I did not know when I have executed which work step. The only place where that was the case was with the package, when I tapped on the package with the cutter knife, it opened, so it was clear to me that I opened it. But with the other two work steps, measuring and drilling, it was not clear to me: Has the work now been carried out or where am I? So, I didn't know the status.” (Interviewee 2 – 4)

In addition, the representation in scenario 2 did not make it apparent to the participants whether they had performed the task correctly or completely. They stated that they could not see any result of their work and whether they ***executed the task successful or correctly***. For example, when drilling, they could not perceive any change in the floor. This was also a reason why they did not know when the task was actually finished.

“Yes, so what was missing was that it works. That you also achieve a result somehow, i.e., in the stone, that the drill spins at some point or so that it simply no longer continues.” (Interviewee 2 – 3)

“But with the drill, I didn't really see any change on the ground, whether it was successful or not, I couldn't recognize that.” (Interviewee 2 – 6)

The findings indicated that even within the two scenarios, feedback was only partially perceived. In scenario 1, there was a clear focus on visual feedback. Auditive and haptic feedback were only perceived by two participants. Scenario 2, on the other hand, indicated that even the perception of visual feedback was not perceived at each work step.

“Haptic feedback not at all. Auditive feedback neither, I didn’t hear anything there either. Actually, purely visual feedback.” (Interviewee 1 – 6)

“I perceived the drill haptically, i.e., it vibrated. The measuring device I actually only perceived visually, and the cutter knife I had also only perceived visual feedback.” (Interviewee 1 – 10)

“No feedback at all. Or, at the cutter, when the box was then gone. […] There was also no vibration on the controller or sound on the ears or anything.” (Interviewee 2 – 7)

“By seeing the product afterwards, the unpacked crane, that it was measured on the screen or the drilled hole, which was then in the ground.” (Interviewee 2 – 1)

The ***tool-dependent factors*** include the tool complexity and the user's tool familiarity. The *tool complexity* can be described by the number of its functions and application options. The *tool familiarity* describes how familiar the user with the tool functions and its application options is, whether it is known from reality, and how regularly it already has been used.

The participants of both scenarios were asked whether a rich tool design would be equally important for all tools. They responded they would differentiate between tools and explained that they would orient towards real functionalities and real operation and would therefore integrate more feedback for the drill than for the laser. For the participants, the necessary feedback is significantly related to the fact that the user must understand what a tool does and for what it is used. With the laser, they stated that it would not be difficult to understand due to its limited number of functionalities, while the drill has a larger number of functionalities and also application areas.

"Well, the laser fits, but in reality, you also just press a button and the thing is ready. With the drill, you have a bit more resistance behind it. It depends a bit more on your fine motor skills. I mean, I just had to press a button. That's not quite as good. And the cutter knife is a little bit easier to show with the remote controls. That actually fits relatively well. The worst is actually the drill." (Interviewee 1 – 3)

"I would differentiate. Of course, you could also spin it so far that you say you are at some point at which you use a tool for several tasks, but for this, you have to set different functions, for example, change the drill from percussion drilling to normal drilling. To have this as haptic feedback that you have changed now. I think that would be very helpful to learn that you have just pressed the switch and that it feels different accordingly. With tools in general to differentiate would be better and not just always have the same vibration when you cut something with the cutter knife or work with the drill. (Interviewee 1 – 4)

Participants of scenario 2 stated that feedback would be helpful to gain a more realistic feeling of tool use, but that they believed it was not necessary for the transfer of process steps. They stated that the 2D tool representation without feedback would be sufficient for a basic understanding of the work steps. However, they prefer a more realistic representation of the tools, which does not necessarily have to be 3D, but better depicts the handling and interaction experience with the tools.

"I think for the normal process understanding even a 2D representation is enough. But I have to say that I think it's better that you try to adapt this from reality, that you really have the tools as tools and not as an image. Also in a certain learning aspect or if you relate to it. But if the goal is only to understand the process and not to go further somehow behind it, I think a 2D representation is also enough." (Interviewee 2 – 2)

"With the cutter, if you then notice you somehow have something like a resistance or something or the controller vibrates a bit, you might hear a noise, that would of course be nice and would make things more realistic, the question is whether you really need that for the goal you are pursuing with it." (Interviewee 2 – 7)

5 Discussion

This research explores how tool design is related to user experience and content transfer in VRTS. The aim of this research was therefore to gain insights into how VRTS can be designed efficiently by focusing on tool design decisions that are aligned with the intended content transfer objective without compromising on the user experience. To address the RQ *(How does tool representation relate to content transfer and user experience in VRTS?*) a two-step research approach with 20 participants was followed which involves experiencing assembly work steps in VR followed by a semi-structured interview.

The findings reveal that factors affecting the transfer of content through and the user experience of VR use can be divided into tool-independent (tool operation, status of the work step, tool handling, and successful execution) and tool-dependent factors (tool complexity and user's tool familiarity) (c.f., Figure 2). The tool-independent factors are primarily related to content transfer, while the tool-dependent factors are primarily related to user experience. Nevertheless, the transitions are fluid and there is a continuous interaction between the user experience and the content transfer.

The ***tool-independent factors*** are largely related to the user's understanding of the VR training content in terms of tasks and workflow. This means that the user must receive information about the status of the tool (on/off), the status of the task (start/end), and the successful and correct execution of the task in order to understand and comprehend the VR content. It has been observed according to Zhang et al. (2005) that this information is conveyed primarily via visual and auditive feedback, with visual feedback being perceived primarily by the majority of participants. The visual feedback should be clear enough to allow the user to draw conclusions about the information mentioned (e.g. the formation of dust or the disappearance of a package). In order to convey the action of the drill, for instance, auditive feedback in the form of drilling sounds can be added (Sikström et al., 2016). The feedback mechanisms used depend on the nature of the tools in reality. The aim is not primarily to make the tool interaction as realistic as possible, but to clearly convey the above information through well-selected feedback.

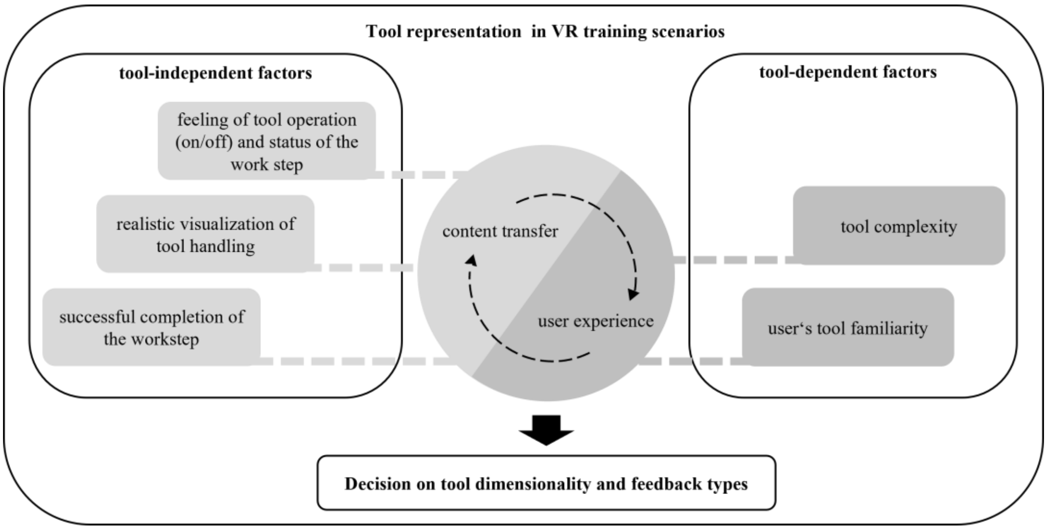

Figure 2. Tool-independent and tool-dependent factors.

The design of tools is also about the question of interaction design. Tools are usable objects whose use allows a change or manipulation of the VR environment and are necessary for the fulfilment of tasks within VRTS. McMahan et al. (2016) suggested to draw on natural actions from reality for the design of interaction within VR to leverage the user experience of familiarity. Appropriately, the findings show that it is important for the feeling of control and operation of the tools in VR that the tool is visualized within the virtual hand, regardless of its dimension. In scenario 2, the tool was displayed at a distance from the hand and also did not follow the tilt and rotation of the participants' hands, which the participants found disturbing. Not only did they themselves describe the VR experience as static, but they also began to move in a particularly static manner. It follows that the visualization of the tools should be in the virtual hands and that the tool should follow the natural hand movements to avoid disturbing the understanding of the content and the user experience at the same time.

Previous research showed that the use of immersive and interactive VR led to higher learning outcomes than 2D desktop representations due to its actionability and interactivity (Johnson-Glenberg et al., 2021). The results also show that the tools should encourage interaction and use. Regardless of how they are designed, they should suggest to the user that they can be used and that they help to accomplish the task. This is accompanied by a feeling of control over the tool, which the participants from scenario 1 described as good, while the participants from scenario 2 communicated an insufficient feeling of control. It can therefore be assumed that a sufficiently visualized feeling of tool handling goes hand in hand with an affording design of the tools. In this way, user confusion is avoided by giving the user a higher sense of control over the interaction with the tool (McMahan et al., 2016).

The ***tool-dependent factors*** include tool complexity and the user's tool familiarity. Huchler et al. (2022) argue that the design of VRTS depends on the underlying real-world work practices that vary in richness and complexity. Similarly, this argument can also be applied to the specific representation of tools in

VR, since tools in reality also vary in complexity and application options. The findings show that decisions regarding tool representation should be guided by tool complexity in order to reduce development effort. For more complex tools, 3D representations should be chosen because they provide a better understanding and experience than schematic 2D representations. For simple tools, whose use is straightforward and familiar to most users, 2D representations are sufficient. Factors that influence tool complexity can be derived from the findings. In this research, three tools were considered, which in reality have different numbers of functions and application options. While the cutter is operated manually, has a function and is a common tool, the laser has one function but is digital. To operate the laser, the user must already have some experience. The drill has many functions, different application options, is electrically operated and the operation requires experience but also knowledge about safety aspects. The above-mentioned characteristics of the individual tools allow an exemplary classification. Accordingly, the cutter would represent an example of a less complex tool. The drill, on the other hand, is an example of a complex tool. The laser can be named as an example of a tool of medium complexity.

How familiar users are with individual tools is determined by the tool-dependent factor 'user's tool familiarity'. The user's tool familiarity can be estimated in advance by precisely considering and defining the target group. In principle, tool complexity and tool familiarity should always be considered in conjunction with each other. Complex tools with which the user group has been working in reality for years, for example, are less of a necessity for representation in 3D than tools that are complex but only used occasionally. Overall, the basis of tool representation questions should first consider the overall objective of the VRTS. VRTS are used, for instance, to familiarize employees with work processes or to train individual workflows (Bellalouna, 2020). Existing research showed that VRTS are less suitable for teaching tool operation (Huchler et al., 2022). At the same time, this means the focus is on teaching and sensitizing for work steps in process form, which the participants confirmed with their impressions. The focus should therefore generally be on designing VRTS that are engaging and appealing, depending on the specific content, and on exploiting their potential for interactive and experiential content transfer. With respect to costs, compromises can then be made that include, for example, a 2D representation of known and simple tools or are limited to visual feedback for understanding the tool-independent factors. It is important that the user experience does not suffer from static and unintuitive tool displays and that users are motivated and encouraged to use the VRTS (Ragan et al., 2015; McMahan et al., 2016).

6 Implications for Practice and Theory

This work has a particularly practice-based motivation. VR has increasingly found ist way into organizational practice in recent years (Torro et al., 2021). Since the development of immersive and interactive VRTS is currently associated with high effort, SMEs in particular are faced with the question of whether the use is economical about the actual benefits (Schwarz et al., 2020). For the development of VRTS, this work can contribute to practice by exploring tool representation alternatives for tools within immersive and interactive VRTS. It supports VR developers on the decision about tool representation depending on both tool-independent and tool-dependent factors. The tool-independent factors contain information that is indispensable for understanding the scenario. This information can be provided to the user primarily through feedback, whereby visual feedback should be chosen as a priority. For the tool-dependent factors, it is crucial to define the target group in advance. The target group can be used to derive conclusions about the users’ familiarity and prior experience with different tools. If the target group is familiar with the tools or works with them regularly in reality, then the representation within VR can be fundamentally less rich without negatively impacting the user experience and content transfer. Nevertheless, the tool complexity should also be taken into account. For example, for a tool with only one function (e.g. cutter), a 2D representation would be sufficient, whereas for a drill with different functions and application options, it would be better to use a 3D representation. In sum, tool complexity and the user's tool familiarity need to be considered in combination to make an appropriate design decision.

For theory, this research addresses a gap in previous research by investigating tool representation alternatives within immersive 3D VR environments. From previous research it can be transferred that a 3D representation of the objects is more realistic, immersive, and engaging for the user. The user perceives the VR experience as a higher quality overall and feels better guided, which has a positive effect on the user experience. Thus, learning success was higher in more immersive and interactive 3D VR environments than in 2D desktop representations, or in 3D desktop VR (Fussan and Hanesova, 2020; Greuter et al., 2021; Johnson-Glenberg et al., 2021). Against the background of a particularly practically motivated question, this work was able to provide a new perspective with different gradations for tool design within immersive and interactive VRTS. The findings demonstrated that not each tool in VRTS has to be designed to be as realistic as possible in order to successfully transfer content. Design decisions can be weighed based on tool-independent and tool-dependent factors. This research can additionally serve as a basis for future research by exploring the focus on design alternatives of objects in VR.

7 Limitations and Future Research

This research has several limitations. First, it has typical limitations of qualitative research such as weak internal validation. 11 participants had no previous VR experience. Some of them explained that it was difficult for them to concentrate on the VR content and the tasks as their focus was mainly on the controls. It was noticeable that these participants also perceived less feedback and found it more difficult to understand the work process. Accordingly, the VR experience appears to have been a particularly influential factor in the understanding and perception of VRTS. Future research can draw on this work and thereby address existing limitations by including or examining different factors: First, two design alternatives were compared in this work. One scenario contained only 2D tool image representations enriched with visual feedback, and the other one 3D tool representations, which were enriched with additional auditive, visual, and haptic feedback. In this sense, the comparison to a 2D representation is missing, which is additionally supported by auditive and haptic feedback, and to a 3D representation that is lacking auditive and haptic feedback. Additionally, it would be interesting to investigate hybrid designs, that use tools of different representation richness and with different feedback types. Participants would also be able to experience the direct comparison between different tool designs. In this regard, future research should explore which feedback types are most likely to be perceived by users or best convey information about the status and correct execution of the work step. Second, it would be important to measure content transfer through the different VR designs by following a quantitative research approach. It therefore appears to be useful to consider more than three tasks. Remembering three work steps does not require a high level of cognitive effort, and at the same time, does not mean that the content is understood (Adams, 2015). In addition, it would be important to pay special attention to participants' prior VR experience, as it seems to be significantly related to focus on the perceived control and feedback. Third, it would be interesting to investigate which tool characteristics make integration into VRTS particularly cost-intensive and complex for VR developers. Therefore, interviews with VR developers could be conducted. Finally, with respect to tool complexity, it would be interesting to investigate whether it is necessary to distinguish between tool complexity in reality and tool complexity in VR. In this context, the impact of different VR controllers on the interaction design and representation of tools in VR could also be explored.

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References

Adams, N. E. (2015). “Bloom’s taxonomy of cognitive learning objectives,” *Journal of the Medical Library Association*, 103 (3), 152-3.

Allcoat, D. and von Mühlenen, A. (2018). “Learning in virtual reality: Effects on performance, emotion and engagement,” *Research in Learning Technology, 26*.

Bellalouna, F. (2020). “New approach for industrial training using virtual reality technology,” *Procedia CIRP*, 93, 262-267.

Bilgin, P., Agres, K., Robinson, N., Wai, A. A. P., and Guan, C. (2019). “A comparative study of mental states in 2D and 3D virtual environments using EEG,” *IEEE International Conference on Systems, Man and Cybernetics*, 2833-2838.

Bowman, D. A., McMahan R. P., and Ragan E. D. (2012). “Questioning naturalism in 3D user interfaces,” *Communications of the ACM*, 55 (9), 78-88.

Charness, G., Gneezy, U., and Kuhn, M. A. (2012). “Experimental methods: Between-subject and within-subject design,” *Journal of Economic Behavior & Organization*, 81 (1), 1-8.

Corbin, J. and Strauss, A. (2014). *Basics of qualitative research: Techniques and procedures for developing grounded theory*, 4th Edition. Los Angeles: Sage Publications Ltd.

de Freitas, F. V., Gomes, M. V. M., and Winkler, I. (2022). “Benefits and challenges of virtual-reality-based industrial usability testing and design reviews: A patents landscape and literature review,” *Applied Sciences*, 12 (3), 1755.

de Oliveira, T. R., Martinelli, T. F., Bello, B. P., Batista, J. D., da Silva, M. M., Rodrigues, B. B., Spinassé, R. A. N., Andreão, R. V., Mestria, M., and Schimidt, M. Q. (2020). “Virtual reality system for industrial motor maintenance training,” *Symposium on Virtual and Augmented Reality*, 119-128.

Downs, L., Francis, A., Koenig, N., Kinman, B., Hickman, R., Reymann, K., McHugh, T. B., and Vanhoucke, V. (2022). “Google scanned objects: A high-quality dataset of 3d scanned household items,” *International Conference on Robotics and Automation*, 2553-2560.

Fussan, C. and Hanesova, V. (2020). “Pre-Testing der Lerneffektivität von 2D-to-3D-Didactics in immersiven VR-Umgebungen,” in: R. Zender, D. Ifenthaler, T. Leonhardt, & C. Schumacher (eds.), *DELFI 2020 - Die 18. Fachtagung Bildungstechnologien der Gesellschaft für Informatik e.V.*, Bonn: Gesellschaft für Informatik e.V., 67-72.

Gibbs, J. K., Gillies, M., and Pan, X. (2022). “A comparison of the effects of haptic and visual feedback on presence in virtual reality,” *International Journal of Human-Computer Studies*, 157, 102717.

Greuter, L., De Rosa, A., Cattin, P., Croci, D. M., Soleman, J., and Guzman, R. (2021). “Randomized study comparing 3D virtual reality and conventional 2D on-screen teaching of cerebrovascular anatomy,” *Neurosurg Focus*, 51 (2), E18.

Heinlein, M., Huchler, N., Wittal, R., Weigel, A., Baumgart, T., and Niehaves, B. (2021). “Erfahrungsgeleitete Gestaltung von VR-Umgebungen zur arbeitsintegrierten Kompetenzentwicklung: Ein Umsetzungsbeispiel bei Montage- und Wartungstätigkeiten,” *Zeitschrift Für Arbeitswissenschaft*, 75 (4), 388-404.

Hepperle, D., Weiß, Y., Siess, A., and Wölfel, M. (2019). “2D, 3D or speech? A case study on which user interface is preferable for what kind of object interaction in immersive virtual reality,” *Computers & Graphics*, 82, 321-331.

Huchler, N., Wittal, R., and Heinlein, M. (2022). “Erfahrungsbasiertes Lernen in der virtuellen Realität - Potenziale und Herausforderungen,” in: Schönfeld, G. and Schürger, B. (eds.), *Betriebliche Weiterbildung in Zeiten der Digitalisierung. Ergebnisse der Telefonbefragung der fünften CVTS-Zusatzerhebung* (Vol. Betriebliche Weiterbildung in Zeiten der Digitalisierung), Bonn: Bundesinstitut für Berufsbildung, 28-32.

Jadhav, M. M., Durgude, Y., and Umaje, V. N. (2019). “Design and development for generation of real object virtual 3D model using laser scanning technology,” *International Journal of Intelligent Machines and Robotics*, 1 (3), 273-291.

Johnson-Glenberg, M. C., Bartolomea, H., and Kalina, E. (2021). "Platform is not destiny: Embodied learning effects comparing 2D desktop to 3D virtual reality STEM experiences," *Journal of Computer Assisted Learning*, 37 (5), 1263-1284.

Kraus, M., Angerbauer, K., Buchmüller, J., Schweitzer, D., Keim, D. A., Sedlmair, M., and Fuchs, J. (2020). "Assessing 2d and 3d heatmaps for comparative analysis: An empirical study," *CHI Conference on Human Factors in Computing Systems*.

Krauß, V., Jasche, F., Saßmannshausen, S. M., Ludwig, T., and Boden, A. (2021). "Research and practice recommendations for mixed reality design - Different perspectives from the community," *ACM Symposium on Virtual Reality Software and Technology*, Osaka, Japan.

Lazar, J., Feng, J. H., and Hochheiser, H. (2017). *Research methods in human-computer interaction*, 2nd Edition. Morgan Kaufmann.

Liagkou, V., Salmas, D. and Stylios, C. (2019). "Realizing virtual reality learning environment for industry 4.0," *Procedia Cirp*, 79, 712-717.

Lledó, L. D., Díez, J. A., Bertomeu-Motos, A., Ezquerro, S., Badesa, F. J., Sabater-Navarro, J. M., and García-Aracil, N. (2016). "A comparative analysis of 2D and 3D tasks for virtual reality therapies based on robotic-assisted neurorehabilitation for post-stroke patients," *Frontiers in Aging Neuroscience*, 8 (205).

McMahan, R. P., Bowman, D. A., Zielinski, D. J., and Brady, R. B. (2012). "Evaluating display fidelity and interaction fidelity in a virtual reality game," *IEEE Transactions on Visualization and Computer Graphics*, 18 (4), 626-633.

McMahan, R. P., Lai, C., and Pal, S. K. (2016). "Interaction fidelity: The uncanny valley of virtual reality interactions," *International Conference on Virtual, Augmented and Mixed Reality*, Springer. 59-70.

Miller, W. and Crabtree, B. (1999). "Clinical research: A multimethod typology and qualitative roadmap," in: Crabtree, B. F. and Miller, W. L. (eds.), *Doing qualitative research*, 2nd Edition, Thousand Oaks: Sage Publications.

Muender, T., Bonfert, M., Reinschluessel, A. V., Malaka, R., and Döring, T. (2022). "Haptic fidelity framework: Defining the factors of realistic haptic feedback for virtual reality," *CHI Conference on Human Factors in Computing Systems*.

Pöhler, L. and Teuteberg, F. (2021). "Closing spatial und motivational gaps: Virtual Reality in Business Process Improvement," *European Conference on Information Systems*.

Ragan, E. D., Bowman, D. A., Kopper, R., Stinson, C., Scerbo, S., and McMahan, R. P. (2015). "Effects of field of view and visual complexity on virtual reality training effectiveness for a visual scanning task," *IEEE Transactions on Visualization and Computer Graphics*, 21 (7), 794-807.

Roettl, J. and Terlutter, R. (2018). "The same video game in 2D, 3D or virtual reality - How does technology impact game evaluation and brand placements?," *PloS One*, 13 (7).

Sarker, S., Xiao, X., and Beaulieu, T. (2013). "Guest editorial: Qualitative studies in information systems: A critical review and some guiding principles," *MIS Quarterly*, 37 (4), iii–xviii.

Schwarz, S., Regal, G., Kempf, M., and Schatz, R. (2020). "Learning success in immersive virtual reality training environments: Practical evidence from automotive assembly," *Nordic Conference on Human-Computer Interaction: Shaping Experiences, Shaping Society.*

Sikström, E., Høeg E. R., Mangano, L., Nilsson, N. C., De Götzen, A., and Serafin, S. (2016). "Shop'til you hear it drop: Influence of interactive auditory feedback in a virtual reality supermarket," *ACM Conference on Virtual Reality Software and Technology.*

Slobounov, S. M., Ray, W., Johnson, B., Slobounov, E., and Newell, K. M. (2015). "Modulation of cortical activity in 2D versus 3D virtual reality environments: An EEG study," *International Journal of Psychophysiology*, 95 (3), 254-260.

Tian, F., Hua, M., Zhang, W., Li, Y., and Yang, X. (2021). "Emotional arousal in 2D versus 3D virtual reality environments," *PLoS One*, 16 (9).

Torro, O., Jalo, H., and Pirkkalainen, H. (2021). "Six reasons why virtual reality is a game-changing computing and communication platform for organizations," *Communications of the ACM*, 64 (10), 48–55.

Vi, S., da Silva, T. S., and Maurer, F. (2019). “User experience guidelines for designing HMD extended reality applications,” *INTERACT 2019*. Springer. 319-341.

Weigel, A., Sauter, L., and Niehaves, B. (2021). “More than you know - An investigation of VR to support tacit knowledge transfer within organisations,” *Pacific Asia Conference on Information Systems*.

Weigel, A., Zeuge, A., Baumgart, T. L., and Niehaves, B. (2021). “Bittersweet virtual reality collaboration: Necessary and sufficient conditions,” *International Conference on Information Systems*. Austin, Texas, USA.

Xie, B., Liu, H., Alghofaili, R., Zhang, Y., Jiang, Y., Lobo, F. D., Akdere, M. (2021). “A review on virtual reality skill training applications,” *Frontiers in Virtual Reality*.

Yildiz, E., Melo, M., Møller, C., and Bessa, M. (2019). “Designing collaborative and coordinated virtual reality training integrated with virtual and physical factories,” *International Conference on Graphics and Interaction*, 48–55.

Zhang, Y., Sotudeh, R., and Fernando, T. (2005). “The use of visual and auditory feedback for assembly task performance in a virtual environment,” *Spring Conference on Computer Graphics*. 59-66.