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The Use of Single-User Immersive Virtual Reality in Professional Training

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The Use of Single-User Immersive Virtual Reality in Professional Training

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Kurzfassung

Diese Arbeit untersucht, wie Single-User immersive Virtual Reality in der Berufsausbildung genutzt werden kann, um sicherheitsrelevante und komplexe Inhalte, vor allem im Rahmen der Lehrausbildung, effektiv und effizient zu vermitteln, und wie diese Technologie in den Unterricht oder die Lehrpraxis integriert werden kann. Durch den Einsatz von VR wird ortsunabhängiges Training und das Erlernen von Inhalten, welche in der realen Welt nicht in dieser Form geübt werden können, ermöglicht. Ein besonderer Vorteil VR-basierter Lernszenarien besteht darin, dass Fehler keine persönliche Gefährdung oder kostspielige Schäden an teuren Anlagen zur Folge haben können. Herausforderungen, Vorteile und Möglichkeiten, welche diese Ausbildungsmethode bringen kann, werden untersucht und Empfehlungen für den Einsatz von VR in der beruflichen Ausbildung werden ausgearbeitet. In einer Fallstudie werden drei Trainingsszenarien untersucht und miteinander verglichen. Elektriker:innen-Szenario (N=109, Lehrlinge), Orientierung im Gebäude (N=41, Krankenpfleger:innen in Ausbildung) und Vorbereitung von Material für eine endotracheale Intubation auf einem Notfallwagen (N=41, Krankenpfleger:innen in Ausbildung) werden mit jeweiligen Auszubildenden getestet. Quantitative Daten werden in Fragebögen erhoben, die Technologieaffinität, Presence, User Experience und Technologieakzeptanz messen. Qualitative Daten werden in semistrukturierten Interviews und Beobachtungen erhoben. Die Studie untersucht, wie die Prototypen von zukünftigen Nutzern wahrgenommen werden, und welche Aspekte für die Integration solcher Ausbildungssysteme in Curricula wichtig sind. Die Ergebnisse zeigen, dass Single-User-VR-Trainings eine willkommene Bereicherung in der Berufsausbildung darstellen und die für die Übung von prozeduralen und sicherheitsrelevante Fähigkeiten in der Praxis sehr gut geeignet sind. Die Studie konnte einen deutlichen Mehrwert in Form von individuellem Lerntempo, mehr Wiederholungen, besserem Fokus und Freude an der VR-basierten Lernumgebung aufzeigen. Neben individuellen Designoptimierungen und inhaltlicher Weiterentwicklung ist die Einbettung des Systems in den Lehralltag die wichtigste Herausforderung. Sowohl die User-Experience als auch der wahrgenommene Mehrwert der Lösung sind wichtige Indikatoren dafür, dass ein System, wie es in dieser Studie entwickelt wurde, von Auszubildenden und Studenten langfristig als Ergänzung zu anderen Lernmethoden genutzt werden kann.

Keywords: Virtual Reality (VR), Training, Head Mounted Display (HMD), Professional Training, Education

Abstract

This thesis examines the use of immersive single-user virtual reality in professional training using head mounted display and hand controllers. VR training offers an advantage in the training of safety relevant tasks and complex procedures, which are currently not practised sufficiently. The goal is to investigate the challenges and opportunities of such training and establish recommendations for the use of single-user VR in professional training. In a case study, three training scenarios are examined. Electricians' scenario (N=109, apprentices), a spatial orientation scenario (N=20, nurses in training) and a medical trolley scenario (N=21, nurses in training) are tested with future users in their educational programmes. Quantitative data is collected in questionnaires measuring affinity for technology interaction, presence, user experience and technology acceptance. Qualitative data is collected in semi- structured interviews and observations. The study investigates, how the prototypes are perceived by future users who are currently completing an apprenticeship or professional training, and which aspects are important for the integration of such training systems into curricula. The results show that single-user VR training is a welcomed enrichment in the professional training, enabling hands-on practice of procedural and safety-relevant skills. The study was able to show a clear added value in the form of individual learning pace, more repetition, better focus and enjoyment of the VR-based learning environment. Besides individual design optimizations and further development of content, embedding the system in everyday teaching, are the most important challenges. Both the user experience and the perceived added value of the solution are important indicators that a system like those developed in this study can be used by apprentices and students in the long term as a supplement to other learning methods.

Keywords: Virtual Reality (VR), Training, Head Mounted Display (HMD), Professional Training, Education

Contents

CHAPTER 1

Introduction

Virtual reality (VR) technology is becoming more available, leading to growing interest in its use in education and professional training [RMN21]. There are many advantages of using VR applications in training. To start with, VR enables location-independent learning of content that cannot be practised in the real-world [MPGK15]. Especially, dangerous and risky tasks can be learned and practised safely in a realistic environment [RMN21] where mistakes are allowed [GGBZ21].

Virtual reality training has already been used in the military context for many years, but present affordable solutions make the technology available to a much greater extent in various areas of application. The interaction in 3D virtual immersive environments is still relatively new and unexplored field of HCI [RMN21]. Therefore, suitable application areas of VR training should be examined with respect to possible limitations [GGBZ21] and accessibility to a broad audience.

1.1 Motivation & Relevance

Currently, apprentices and trainees in various fields do not have enough opportunities to practice safety-related tasks. A particular advantage of VR training is that one can make mistakes without causing damage, endangering themselves or others, repeat the effort, and take as much time as needed [RMN21]. This is important since repetitions and practice are crucial for acquiring new skills [JK18].

A systematic review of the effectiveness of VR HMDs in professional training covering a publication period of 30 years conducted by Renganayagalu et al. [RMN21] points out that the majority of reviewed studies were conducted under controlled lab conditions, using university students and staff as participants. This problem is also addressed in the systematic review of VR serious games and evacuation training by Feng et al. [FGA+18]. The problematic aspect is the missing focus on the target groups and the real-world application. Moreover, the training should be evaluated considering its embedding in the real-world. Most of the reviewed studies by Renganayagalu et al. [RMN21] show positive effects of using VR with HMDs, but there is still missing evidence on how specifically should this technology be used in training [JK18]. It remains unclear whether training in virtual environments using HMDs leads to better learning outcomes than the nowadays commonly used methods [MPS+20], especially when applying the newly acquired knowledge in real-world contexts [MBGM19].

Learning with VR leads to higher user motivation [SFLRS18] and interest [FGA+18] and thus more efficient learning with shorter training time, higher self-confidence and easier recovery after errors than in real-world environments [PM08].

Furthermore, possible barriers to VR training should be examined more closely to be eliminated in the future. The use of VR should be investigated in an authentic setting as a part of a training programme [JK18].

Evidence about how VR training is currently being integrated or could be integrated into curricula, is missing. Innovative technologies, like VR, should not be adopted before considering their learning objectives, activities, assessments and integration within curricula. They cannot replace practical experience [MBGM19] but can enrich current teaching methods [PLS+21]. Virtual reality in education is still used experimentally and is not part of the regular curricula [RMFW20]. There are no defined best practices [JK18], no recommendations for the design [WRSF20] and use of VR in training [WWW+18], also standardized rules for scenario creation are missing [LDLPM21]. Therefore, it is necessary to investigate VR training in an authentic context, to establish best practices.

Based on the addressed research gaps and challenges, the following two research questions are derived:

1.1.1 Research Questions

- **RQ1:** What are the opportunities and challenges of using single-user VR HMD in current professional training in terms of accessibility, learning outcomes, acceptance factors, and motivation to use the technology?
- **RQ2:** How can single-user VR HMD training be effectively and efficiently used in professional training, and which guidelines should be followed when designing and applying the training in a real-world context?

1.2 Aim, Context & Scope of the Thesis

The aim of this work is to examine how safety-relevant content can be conveyed efficiently and effectively in vocational training using single-user VR HMD training and investigate under which conditions it can successfully be integrated into teaching in practice. Despite the challenges of introducing novel learning methods, virtual reality is a promising way of enriching the current education system [BKEE18].

In the projects included in this work, functional prototypes of single-user VR applications using HMDs are developed, tested and evaluated in the context of vocational schools and training facilities as a part of the current teaching programmes. Conducting studies with participants similar to the groups, which will use the system in the future, leads to higher data quality and better results in application [RMN21]. Therefore, all participants in our experiments and workshops are future users with experience in the respective field.

We examine how such training affects learning whilst comparing two groups learning the same task, one using VR and the other using printed materials. One of these tasks focuses on spatial orientation, and the other on learning and applying procedural skills. The second project also focuses on procedural skills, has similar goals but a different experiment design. All three experiments overlap in the used metrics, questionnaires, and interview questions. In addition, user experience, accessibility and usability of the system are examined from the viewpoint of different user groups. The goal is to identify and analyse barriers and challenges of the training to remove them in the future.

Another goal is to identify suitable teaching and learning paradigms for VR training which take into account the real-world context of the training. Therefore, it is necessary to assess the acceptance among the trainers and their openness to the adoption of new technology, so as to find possible issues and prevent them. There is missing evidence on how can VR be integrated with already existing educational programs and associated e-learning [WWW+18]. The aim is to look at this problem as holistically as possible and jointly examine and compare the use of VR training in different areas, and based on the findings, formulate recommendations that make it easier to develop future VR training accessible for a wide variety of users, both learners and teachers, leading to the utilization of the potential of this novel technology in professional training in the long term.

An overview of the identified research gaps and challenges linked to each other as proposed solutions and contributions can be found in figure 1.1.

Figure 1.1: Research gaps identified in the literature with links and connections to the contribution of this work.

1.3 Methodology

This thesis is based on two national research projects focusing on the possibilities of using virtual reality in professional education, on the example of training for electricians and medical staff. The methodical process is visualized in figure 1.2 and can be divided into the following steps:

- In the initial phase, relevant literature focusing on learning and training with virtual reality is gathered by searching ACM Digital Library, Google Scholar, Semantic Scholar and using the materials provided in lecture 193.05 User Research Methods at TU Wien.
  The search terms are created by using and combining the following keywords: *virtual reality, VR, immersive VR, education, vocational training, emergency training, serious games, simulation, electricians, industry, head-mounted display, HMD, user study, experiment, presence, motion sickness, technology acceptance, TAM3, usability, user experience, feedback.*

  In the first step, literature reviews and empirical studies describing experiments with immersive virtual reality for the training of electricians or vocational training in industry, nurse training and education in general (recent studies using head-mounted displays) are collected and analysed. Regarding definitions and models, the original literature and its reviews are taken into account. Additionally, relevant studies mentioned in the reviewed literature are also included. Suggestions on relevant literature were given in the proposals of the projects, including the following articles: [BSSFM18, BLB+17, BLT+14, LBR+15, RSSS18, SFSS17, SFLRS18].

- In parallel with the literature search, workshops with future users and experts are conducted. The information gathered during this process is used to formulate scenario requirements and specify their focus.

- In the next step, the scenarios are designed and implemented in a continuous development process. Based on these requirements, a prototype scenarios are developed. These prototypes are tested and discussed with experts in each iteration.

- The three experiments which build up this case study are conducted with groups of electrician apprentices and nurses in training as part of their educational programmes. The scenarios are evaluated using qualitative and quantitative methods to get more in-depth insights and detect recurring patterns. Qualitative data in the form of semi-structured interviews and observations, and quantitative data in the form of questionnaires and task-related metrics are collected.

- This data is analysed using methods recommended or commonly used in combination with the corresponding questionnaires and a data-types. For interviews and other qualitative data, the content analysis by Mayring [May00] is applied.

- In order to meet the goal of formulating guidelines for single-player VR HMD professional training and its integration into curricula, the data resulting from the three experiments are searched for reoccurring patterns, similarities, differences and their possible causes. Challenges and opportunities, technology acceptance and motivation factor for using VR in professional training, are identified and discussed.

1.4 Structure of the Work

This thesis is organized as follows:

- In chapter **2 Related Work**, the definitions and explanation of common phenomena are given, followed by a section listing related experiments and studies applying VR in the fields of industrial, medical and safety training. These studies are grouped by the skills they focus on, procedural and orientational. Afterwards, findings set up by multiple sources are summarized. Relevant literature discussing and comparing evaluation techniques in virtual reality training is described and summarized. Based on the literature, suitable metrics for the experiments are chosen.
- Chapter **3 Approach** describes why the case study approach was chosen and how it's applied. Then, the projects selected for the case study are described in a greater detail. Their goals, structure, background and initial planning are discussed, including the workshops with experts and brainstormings leading to the formulation of scenario requirements.
- The next chapter, **4 Case Study**, focuses on the methodology of each of the three experiments, describing the study design, the procedure, the characteristics of the participants and lists collected data and related analysis methods. The VR scenarios are depicted and described in this chapter.
- Chapter **5 Results** lists all the results from data collected in the case study, organizing them accordingly to the experiments, including visualizations of the data collected in the questionnaires and interviews, so as the imagery collected with eye-tracking glasses during one of the experiments.
- Chapter **6 Discussion** interconnects the findings from the results, interprets them and focuses on their practical and theoretical implications. Based on the obtained insights, recommendations for the use of single-user immersive virtual reality training in professional education are formulated.
- Chapter **7 Conclusion** summarizes and reflects the research process and formulates an outlook on possible future application and extension of the training scenarios. Further, open research questions are considered.
- In **Appendix** all materials used during the experiments are listed: questionnaires, interview questions and training materials.

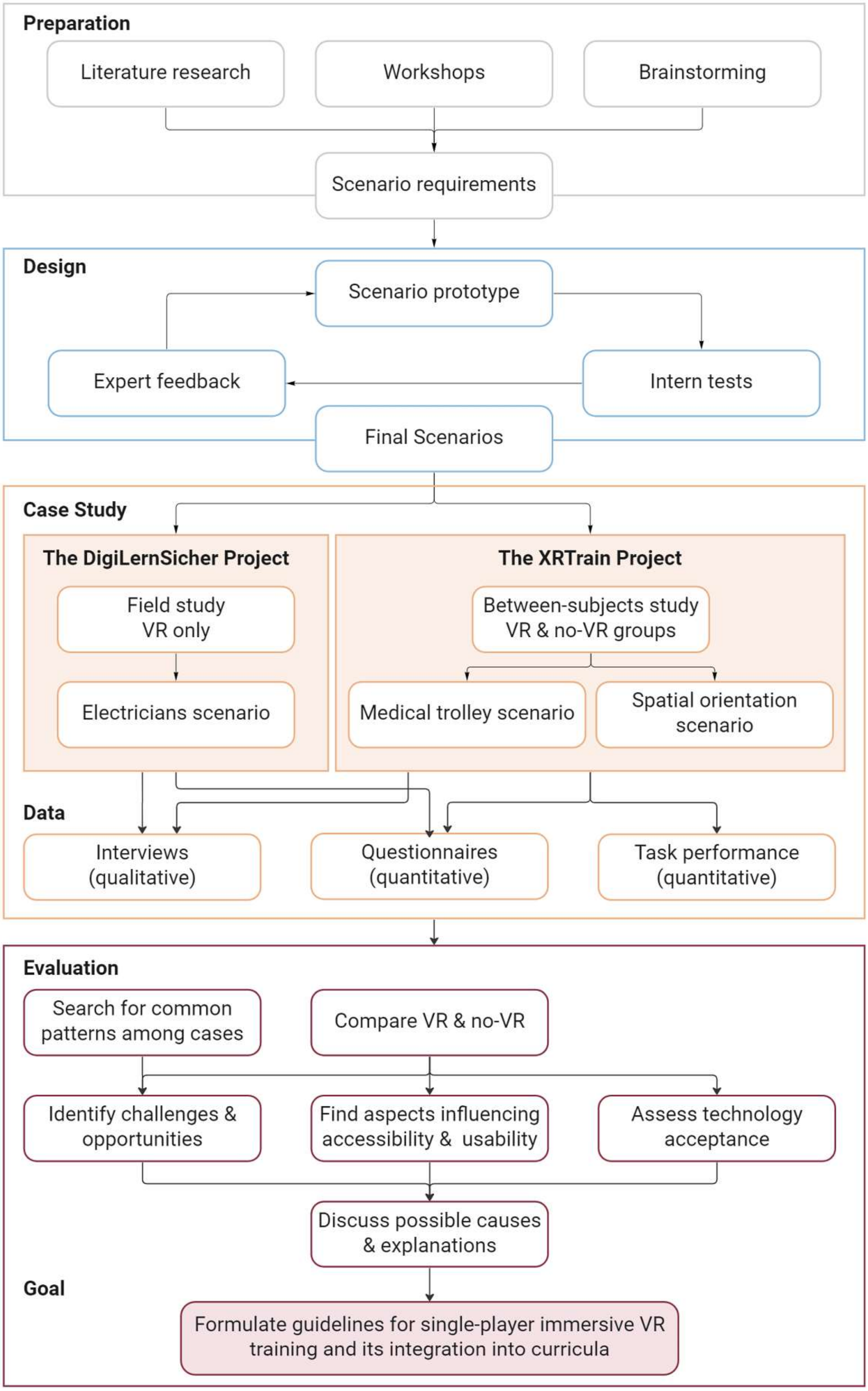

Figure 1.2: Visualization of the methodology and its areas of application and steps.

CHAPTER 2

Related Work

2.1 Key Concepts in Virtual Reality

2.1.1 Definition of Virtual Reality

In 1965, Ivan Sutherland proposed the ultimate display, a device that would make a computer-generated world look, sound, smell, taste and feel real [Man13]. In his paper [Sut65], he envisions what can be achieved with various modes of interaction in a computer-generated world. By creating and interacting with worlds that do not comply with the physics of the real-world, new and existing concepts can be given a completely new form of visual representation, making it possible to get familiar with new concepts.

His vision goes even further: "The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal. With appropriate programming, such a display could literally be the Wonderland into which Alice walked." [Sut65, p. 2].

The term virtual reality itself was introduced by Jaron Lanier in 1987 [Man13]. NASA uses the following definition: "Virtual reality is the use of computer technology to create the effect of an interactive three-dimensional world in which the objects have a sense of spatial presence." [NAS].

The definition given in Britannica: "Virtual reality (VR) is the use of computer modelling and simulation that enables a person to interact with an artificial three-dimensional (3-D) visual or other sensory environment."[Low].

Biocca & Delaney [BD95, p. 63] define virtual reality as "the sum of the hardware and software systems that seek to perfect an all-inclusive, sensory illusion of being present in another environment”.

Mandal [Man13] describes virtual reality as a three-dimensional computer generated environment, where the user can move through and interact with objects and manipulate the environment in real-time, usually by the use of hand tracking systems. There are various devices on which this can be experienced [Man13]. Furthermore, the application range of virtual reality technologies has no fixed border and thus can be used in many areas [GGBZ21]. The concept of VR is also closely associated with immersion, presence and interactivity [RMFW20].

2.1.2 Presence & Immersion

The terms presence and immersion are used to describe the sense of inhabiting virtual simulated spaces, which emerges through the user's imagination but also through the interaction between the user and the machine. However, there is a lack of consensus regarding the terminological distinction between these two terms. In literature, these terms are sometimes used interchangeably, complementary and even suggesting conflicting meanings [Cal13].

The feeling of *being there* in the virtual environment, is referred to as presence [LBR+15]. Another definition is based on the following concepts: experiencing virtual environments is mediated through various devices, and the feeling of this experience being non-mediated, creating the illusion of real-world, is described as presence. For a positive user experience of virtual reality, it is very important that the user feels being present in the environment. Navigation method and the level of immersion also have influence on presence [LBR+15]. A significant relation between presence and usability was found by Busch et al. [BLT+14]. Presence also positively influences user acceptance [SLEL+20]. High feeling of presence and immersion have a positive influence on the perceived usefulness of the system [BMA+19]. Since inducing a high feeling of presence in virtual environments is desired, better understanding of presence, including its causes and effects, are important for the development of new technology and training scenarios [SLEL+20]. A brief visual summary of these findings regarding presence can be found in figure 2.1. The term immersion is being used in various context from art, cinema, literature and music to computer games, and thus suggesting different meanings. Among researchers, there are multiple views on how immersion should be viewed. One group perceives immersion as a technological attribute that can be objectively evaluated. The other sees immersion as an individual and subjective phenomenon [Cal13]. In this work, immersion is to be understood as the technological attribute and presence as the psychological response induced by immersion [Cal13].

Immersion is induced by surrounding the user with images and sounds that feel *authentic* in a dynamic way, following the user's position and moving so that the user remains in the middle of the environment [WWW+18]. Immersive VR includes HMDs and CAVEs. Non-immersive, sometimes referred to as desktop VR, is the simplest type of VR where the virtual world is visible on one or multiple screens [Man13]. Presence is usually measured immediately after the VR experience by standardized questionnaires [SKHH19].

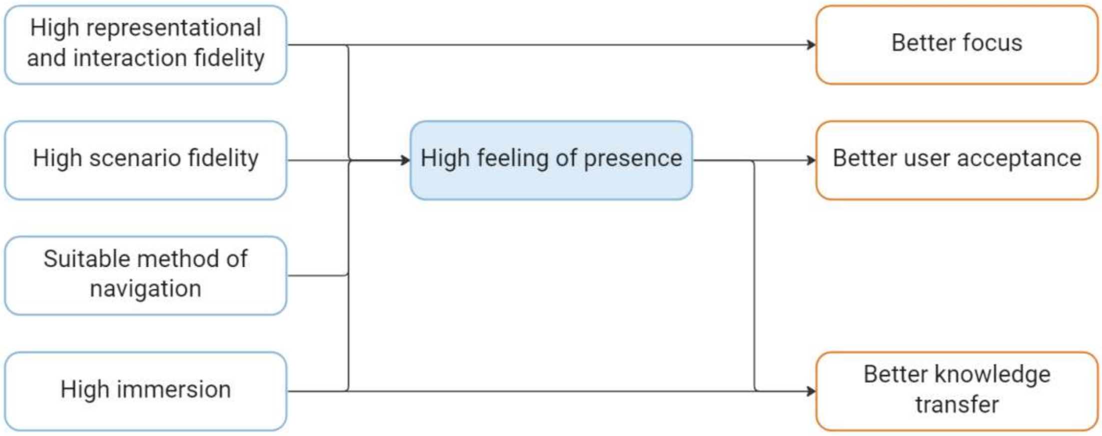

Figure 2.1: A visual summary of the main findings regarding presence.

2.1.3 Fidelity

Fidelity plays an important role in VR applications. There are three types of fidelity being most commonly described in the literature: display fidelity, interaction fidelity and scenario fidelity (storytelling) [BC18]. High display fidelity makes it easier to focus and retain attention, however, this does not imply higher perceived presence [Cal13]. Different levels of display fidelity in a VR safety training scenario were examined by Buttussi et al. [BC18], with the conclusion that high display fidelity is linked to higher feeling of presence and increased engagement, but does not lead to better learning outcomes. Therefore, it remains an open question, if higher interaction fidelity can improve learning outcomes, especially in situations where users practice physical tasks. Moreover, the role of scenario fidelity needs further research [BC18]. In addition, high fidelity and realism leads to higher engagement with the learned topic [FGA+18].

2.1.4 User Experience & Usability

The ISO 924-210 defines user experience as a "person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service" [ISO10, 2.15]. User experience plays an important role in VR and must be considered in the design and evaluation of virtual environments [SRKS20]. Positive user experience has an influence on other aspects, the more users enjoy using the system and have a sense of understanding, the more they want to use it again [BMA+19]. Usability is defined as the "extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" in the ISO 924-210 [ISO10, 2.13]. Usability of a system is negatively influenced by the perceived effort, frustration, anxiety and subjective workload, so that an environment which can be handled with little effort is perceived as more usable. However, environments which require attention and mental work are more enjoyable [BMA+19].

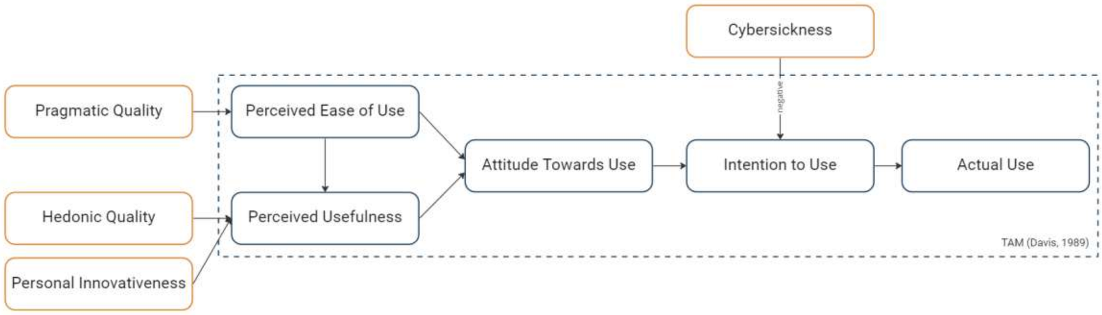

Figure 2.2: The Technology Acceptance Model by Davis [Dav89] (dark blue) and its extension by Sagnier et al. [SLEL+20] (orange).

2.1.5 Technology Acceptance

The technology acceptance model (TAM) aims to explain and predict user behaviour towards technology, based on perceived usefulness and perceived ease of use [Dav89]. Perceived usefulness describes users' belief, that this technology will help them perform their job better. Perceived ease of use describes users' belief that the use of the technology is free of effort [Dav89].

TAM has been adapted and extended multiple times. Venkatesh et al. [VB08] present an extended model which takes into account further variables. According to this model, experience mediates the negative effect of computer anxiety on perceived ease of use, so that increasing experience weakens the effect of computer anxiety. Also, self-efficacy and intrinsic motivation influence the perceived ease of use [VB08]. Sagnier et al. [SLEL+20] tested an extended technology acceptance model focusing on user acceptance of virtual reality, combining the TAM with user experience. This model was tested with 89 users performing an assembly task in VR. Pragmatic quality, hedonic quality, personal innovativeness and cybersickness were integrated into the original TAM (see figure 2.2). Pragmatic quality is the perceived ability of the product to support the achievement of goals. Hedonic quality, includes enjoyment, playfulness, aesthetics and induced emotion. Personal innovativeness describes user's attitude towards new technology. In this study, presence had a positive effect on intention to use the technology, however, this effect was not significant. Pragmatic quality positively influences perceived ease of use [SLEL+20]. Hedonic quality and personal innovativeness have a positive effect on the perceived usefulness. In this model, pragmatic and hedonic quality were measured by the AttrakDiff questionnaire by Hassenzahl et al. [HBK03].

Nowadays, TAM and its extensions are the most commonly used models for user acceptance. Moreover, technology acceptance among the future users should be examined when planning to use VR in education or training [SLEL+20].

2.1.6 Simulator Sickness

Simulator sickness, sometimes referred to as cybersickness, is induced by mismatching sensory signals the body is receiving [RMN21]. It is characterized by one or more of the following symptoms: feeling of general discomfort, fatigue, headache, nausea, eye strain, difficulty focusing, difficulty concentrating and blurred vision [BWK20]. The symptoms of cybersickness can be mitigated by limiting the mismatch between the virtual environment and the experienced movement as much as possible [SRKS20]. Simulator sickness has a significant negative impact on the willingness to use the virtual environment [SLEL+20]. Additionally, users experiencing more simulator sickness think they have not the capacity or knowledge to use the environment [BMA+19].

More recent studies observe less simulator sickness cases than earlier studies, presumably due to the advance in VR technology. Also, the right way of navigation and interaction helps to prevent simulator sickness [FGA+18].

2.1.7 Limitations of the Technology

Nowadays, the development of simulations for use in HMDs is still quite expensive. The solutions are tailored for specific use-cases, which usually cannot be repurposed. Therefore, there are still no standardized rules for the design of VR training simulations [LDLPM21]. Furthermore, a number of individual aspects might influence the training outcomes, such as age, experience with given technology [SRKS20], and openness to new technology.

The technology used in training is strongly dependent on the price of the device. The increased interest in using HMDs in training, is related to significant developments in the quality of image leading to high fidelity, high immersion, low latency, and relatively low cost solutions [RMN21]. Even though the development of the technology has made remarkable progress in recent years, it is still very difficult or nearly impossible to introduce realistic haptic feedback and tactile sensations [MPGK15], therefore the precision and details needed for a correct assembly of elements might be underestimated [SRKS20].

Moreover, the interaction in 3D virtual environments is still relatively new and unexplored field of HCI, whereby different interaction and input methods lead to varying user experience. One additional problem of the currently used affordable HMDs is that they have been designed for gaming and entertainment applications, and they don't foresee an uninterrupted use, for few hours, as other traditional simulator that have been designed for training [RMN21]. Even though simulator sickness is rare in modern systems, visual discomfort, including blurry vision and the weight of the HMD itself, are still a limiting factors [BMA+19]. Moreover, training in VR might still be cumbersome and lead to high mental load [MBGM19].

2.1.8 Types of Virtual reality

CAVE

Cave Automatic Virtual Environment (CAVE) consists of a room where the image is projected on the walls, optionally, on the floor and the ceiling. In addition, the users wear glasses to see the place in 3D. This technology is less flexible, more complex and costly, making it less popular than HMDs. An advantage of this system is the integrated walkable area, which enables natural movement (walking) in the virtual environment. CAVE systems are sometimes not considered immersive, since the user can still recognize the walls of the non-virtual environment [RMFW20].

Head Mounted Displays (HMDs)

The ISO standard 9241-380 [ISO19, 3.1] describes a head-mounted display as a "device which displays stereo views of virtual reality. It has two small displays with lenses and semi-transparent mirrors which can adapt to the left and right eyes".

Immersive VR using HMD is the most widely used technology for VR applications, since it is less complex and cheaper than CAVEs and offers higher level of immersion than desktop VR. HMDs work as input and output devices at the same time thanks to sensors including gyroscope, motion tracking and accelerometers. They can be equipped with additional sensors, such as cameras enabling augmented reality or eye-tracking system. The output channels of the HMD are two displays and audio. Nowadays, HMDs are the most popular kind of immersive VR, and even today's affordable versions are highly immersive and easy to use, which contributes to the growing interest in using them for various purposes. [RMN21].

2.2 Virtual Reality in Professional Training

Virtual reality was first being used for training in the military context and it took a long time for its introduction to other fields, especially due to the high cost of the necessary equipment. Nonetheless, since the price of the devices enabling VR experience is sinking and properties of the available hardware are improving significantly [Car17], the area of possible applications is growing.

Training in virtual reality can simulate a specific segment of reality [GGBZ21] or include imaginary worlds [Sut65], both in a hands-on manner and in a safe environment. VR applications are getting even more interesting for education and training due to their interactive and immersive nature. However, VR in education is still being used only in an experimental way, not being included into regular curricula [RMFW20]. Renganayagalu et al. [RMN21] reviewed literature on effectiveness of VR-based simulation training from the past 30 years. They describe the trend of using VR, which was already considered a viable technology for training and education in the 00s. However, the advancements in computing power, display technology and 3D gaming made VR technology more prevalent in the consumer market [RMN21].

VR training is especially suitable for contexts where mistakes can result in harm to oneself and other people, cause damage, or where training in real environment is not possible, for example preparing for emergency situations or working with not yet existing products [SRKS20]. There is a growing interest in using VR simulations in vocational and safety training because critical and dangerous tasks can be practised in a safe and realistic environment [GGBZ21]. Such simulations can offer various scenarios with multiple levels of difficulty, personalized content and feedback.

Among further advantages of training in virtual environments, Schwarz et al. [SRKS20] addressed reduction of fabrication time, reduction of time-to-market and possibly lower cost of such training compared to traditional means of training. In addition, the training can be repeated frequently, as many times as needed. Studies conducted by Tanaka et al. [TPG+21], Górski et al. [GGBZ21] and Makransky et al. [MBGM19] all confirm that VR training motivates users to actively experiment and interact with the environment. Tanaka et al. [TPG+21] suggest that manipulating objects helps to gain and organize knowledge. Such environment also supports individual learning approaches with less pressure than traditional training [TPG+21]. Using a VR simulation can enrich the learning process [PLS+21] and increase the engagement of the trainees [SFLRS18].

Learning with VR can lead to higher motivation and interest [MBGM19], and hence to a more efficient learning, fewer hours spent training, higher confidence and easier recovery from errors than in real environments [PM08]. Also, representational fidelity, interaction with objects and environment, and the sense of presence lead to a better transfer of knowledge to real world conditions, and thus better application of the knowledge. The interactive and immersive environment enables to learn by experimenting, manipulating and exploring in real-time. However, it is important to distinguish between the VR applications for school education, especially primary education, and job oriented professional training, which are more complex and difficult to measure [RMN21].

In theory, VR enables individual learning without a trainer since the environment itself can offer objectives, guidance, and feedback [PLS+21]. However, students' and trainers' motivation are related [PM08]. Therefore, it is beneficial if the VR training offers guidance and support by the trainers [MPGK15]. Such technologies need to be thoroughly integrated in the curriculum and should not replace other learning methods or be used by students without guidance [BMA+19].

In the systematic review by Renganayagalu et al. [RMN21], 59 out of 60 reviewed studies reported positive effects of the VR Training with regard to user acceptance. VR training is predominantly used for training memory and procedural skills, followed by spatial task related and orientational skills [RMN21]. In industrial setting, the learning mostly focuses on procedural skills for assembly and maintenance, where the trainees learn to recognize and remember parts, so as the correct order, orientation and the single steps of the procedure [GGBZ21]. Another important task learned in VR is the optical inspection of parts. Evidence was found, that high immersion of the VR application and spatial memory skills are related [RMN21].

2.2.1 Orientational Skills

Krokos et al. [KPV19] conducted a user study with 40 participants, investigating the effect of spatial information representation on memorability and recall. Inspired by the mnemonic technique of memory places, a virtual 3D model of a castle with allocated information was created. A group using VR with HMDs, a group using a desktop application with a 3D model and a control group with a list of items without any guidance how to remember them, participated in the experiment. Then, information recall and confidence of learning, were compared. The VR group could better recall the information and stated that they felt more focused. The results also showed, that the feeling of presence in the environment was of high importance. The majority of the VR group stated that the spatial awareness enabled through the HMD contributed to their success, and they remembered the position of the object relatively to their body, which helped them to remember it better. Even people with little to no HMD experience performed better in the VR than in the desktop version, and all but two participants stated they preferred the HMD over other devices. Moreover, 70% of the participants mentioned a superior sense of spatial awareness enabled by the use of the HMD. The HMD group had a statistically significant improvement in recall accuracy compared to the desktop group [KPV19].

People acquire knowledge about space by moving around and interaction with their environment. They perceive information from multiple senses simultaneously and focus on landmarks which they can remember [KKC+21]. Nowadays, HMDs offer high feeling of immersion and presence, but the perception of the environment is mostly visual and auditory, leaving out the other senses necessary for acquiring spatial knowledge.

König et al. [KKC+21] conducted an experiment with 22 participants, studying a group discovering a virtual village using an HMD and a control group using an interactive map on desktop to explore the environment by walking as pedestrians. The environment consisted of 213 buildings and 216.000m2. They examined the effects of different media (VR and non-VR) on spatial learning. In the end, the participants completed various tasks measuring the accuracy of relevant and cardinal orientation of landmarks. The results show that the participants gained similar knowledge in both learning methods. The group using VR performed better at judging straight directions between landmarks. On the other hand, the non-VR group was better at estimating cardinal directions [KKC+21].

Schrom-Feiertag et al. [SFSS17] conducted an experiment consisting of way-finding tasks in a CAVE virtual environment. An indoor guidance system of a large train station was evaluated by using eye-tracking, gaze analysis and creation of attention maps. The main advantage of the CAVE is the natural way of movement due to a walkable area, and thereby a lower risk of simulation sickness. The experiment was conducted with 24 participants, none of them having any knowledge of the area. The task consisted of walking along waypoints and finding specified locations. The participants were allowed to use a paper map and ask the workers of the train station (avatars). They were navigating freely without predefined routes. The task took between 15 and 20 minutes, however, the time spent in VR in one go was kept under 10 minutes to reduce cybersickness. Task performance measures including completion times, travelled distance and physical behaviour including walking speed, moving trajectory, location of stops and looking around were assessed. Also, user's perception of presence was measured. The results show that virtual environments are suitable for conducting way-finding studies [SFSS17].

2.2.2 Procedural Skills

Electricians

An experiment comparing different modes of interaction and movement in a prototype VR training system for electricians was conducted by Górski et al. [GGBZ21]. The goal of the experiment was to find an optimal combination of interaction techniques and assess the suitability of such VR simulation for the future training of electricians working on the facility. Three methods of navigation and three methods of interaction were tested with 30 participants. The system was running on HMD, Oculus Rift CV1 and HTC Vive. The participants practised two different scenarios, both of them being standardized procedures consisting of a fixed number of steps. The first scenario focused on the training of switching operations at the virtual station, preparing the system for the switch off of a 110 / 15kV transformer. The second scenario simulated placing a non-live cable into a live distribution device. An avatar character in the scenario provided guidance in the form of short tips, which were shown on a flipchart or directly spoken. The implementation times and the number of hints among different setups were compared. The participants also completed a pre- and a post-questionnaire, including an overall assessment of the VR application and its usability. Overall, 90% of the participants rated the technology as useful, and 54.5% stated, that such trainings could replace traditional trainings. Additionally, no one rated the technology as useless [GGBZ21].

A VR training system for electricians working on substation was designed and examined by Tanaka et al. [TPB+17], in order to assess the applicability of a VR training as a supplement to the current trainings, since the goal was to prepare the operators for working at critical infrastructure where any case of emergency must be solved quickly and without any errors and consequences for the integrity of the distribution. There were 70 workers of the substation, taking part in the study. They were also included in the continuous development of the VR simulation, giving expert knowledge. In the scenario, the users were asked to walk around the facility and check the equipment for errors. Since this experiment concluded that such a training is a suitable supplement to the traditional training, further studies were suggested [TPB+17].

Currently, the training of electricians and networks operators does not include enough practical training and focuses predominantly on theoretical knowledge. Nevertheless, practical training is indispensable for adopting best practices and the prevention of accidents. In a follow-up study, effects of different ways of movement and the general applicability of such a training were examined. There were three possible ways of movement in the scenario: free movement mode, teleportation and 7-mile steps. Teleportation and the 7-mile steps were rated similarly well, and also induced less simulator sickness than the free movement mode. The teleport mode is suggested to be used as the default option [TPG+21].

Healthcare

Virtual Reality training is already widely accepted in the medical domain, however due to longer application and research of VR in healthcare, the VR systems used for such training are more sophisticated and specialized, therefore HMDs are not the dominant system being used in medical training [RMN21].

Plotzky et al. [PLS+21] conducted a systematic review of the use of VR in nurse education and included 22 papers. The skills trained in these simulations were categorized as follows: systematic procedure training (9), emergency response training (5), soft skills training (3) and psychomotor skills training (3). Systematic procedure training was the most common and included tasks such as preparing a table for operation, preparing an injection or learning the procedure for wound treatment. In general, VR makes a suitable tool for procedural training since it enables repeated training which can be varied and practised without contact with the patient or needing equipment which might not be available. Compared to other disciplines in the medical education, VR training in nursing education is relatively new and not investigated sufficiently. Additionally, using VR could make the nursing education more attractive [PLS+21].

Bracq et al. [BMA+19] conducted a study with 29 participants (13 nurses and 16 non-expert users) to assess the acceptability and usability of a procedural VR training in nursing education. In the experiment, the participants should prepare an instrumentation table for craniotomy. First, they got familiar with the interaction in the scenario by watching a 3 minutes instruction video. Then they practised the movement and navigation in a pre-training VR scenario in order to reduce stress and mental load. Finally, they performed the task in a 20-min session. The goal was to correctly arrange instruments for craniotomy handed to them by a virtual nurse. Data were collected in a pre- and post-questionnaire and in an interview. Personal innovativeness, familiarity with video games and virtual reality, mental load (NASA TLX), presence, cybersickness (SSQ) and task completion times were assessed. The results show that interest in VR, which was assessed before and after the VR training, significantly increased after the training scenario. Also, mental load and required attention positively correlate with the hedonic motivation. Age, gender and experience with games and VR did not affect the user acceptability. Further research should investigate which effects do such trainings have on the procedural skills in the real environment [BMA+19].

Butt et al. [BKEE18] conducted a survey assessing the usability and user reaction to a game-based VR simulation for urinary catheterization training. Nurses have only limited opportunities to practices procedures before performing them on patients. Current learning is heavily based on checklists and memorization. In the experiment, 20 undergraduate nursing students were assigned to a VR HMD and no-VR conditions. The VR scenario utilized interactive gloves, allowing the learners to use their own hands for interaction. The participants had one hour to practice of urinary catheterization with immediate feedback from an expert in both groups. Data regarding usability (SUS), enjoyment, engagement, comfort, likelihood to practice and preferred device for practising were assessed. Also, the training sessions were transcribed and coded. These observations were considered together with the results of the questionnaires to find common topics. The willingness to practice repeatedly was high. In a retention test conducted two weeks after the training, both groups performed similarly. The system was received well and results show that students are willing to use this tool in practice [BMA+19].

Safety Training

Another important field of VR training application is safety and emergency training. The main advantage of VR in this field is the safety while training and the variety of training scenarios that can be used, combined with lower cost compared to traditional training methods [RMN21]. The training of emergency situations is an excellent example of application, since it is very difficult to realistically simulate such a case in another way [SRKS20]. VR enables a safe hands-on approach in the initial phase of training. In this way, the trainees can practice as much as they need, try different options and actively participate in various situations. Disaster preparedness training is already quite common, however, the current training methods are often non-immersive. Natural movement and walking is necessary for inducing physical excitement and stress and so making the experience more realistic. Systems enabling high fidelity are still very expensive and thus only being used by military and not in the training of first-responders [MPGK15].

Feng et al. [FGA+18] systematically examined literature regarding serious games and evacuation training using virtual reality. Currently, the learning methods are not very efficient in transferring knowledge. In the traditional methods, feedback, and especially emotions nearing the real situation are missing, and therefore this training is very different from the real situation. In addition, traditional training require high cost in terms of staff, space and time and are difficult to organize. Training with VR can be very helpful in supporting presence and so improving the emotional engagement. There are many aspects showing, that using VR in the training of emergency situation is very beneficial: participants can better recall their experience, they can directly interact with the environment they are immersed in, which is more engaging and motivating than other forms of training, and they can get immediate feedback and quickly learn from errors. In addition, the data collected during the training in virtual environments can be used to study the behavioural patterns more closely. Virtual reality together with serious games enable otherwise dangerous situations to be studied [FGA+18].

Fire safety is an important application area for VR trainings, since the virtual environment enables to simulate situations in a highly realistic manner and therefore increase the engagement and emotional response. A study comparing VR and traditional (a non-interactable video material) training of using a fire extinguisher was conducted by

Lovreglio et al. [LDR+21]. They conducted an experiment with 93 participants which included a pre-test to assess the current level of knowledge, the training itself, a post-test immediately after the training and a retention test 3-4 weeks after the training. They measured knowledge acquisition, knowledge retention, self-efficacy, recommendation efficacy and recommendation simplicity. The results show a significant knowledge gain right after the training in both groups, however, the VR group performed better in the knowledge gain test and shows significantly higher knowledge retention. The self-efficacy decreased significantly for the video group after the 3-4 weeks, but the VR group did not show any decrease. VR is suitable for supplementary use to other types of trainings, as the majority of the participants would recommend the VR training over the video training. The results indicate, that VR training is more effective than a video training in the long term, however, the VR group might have overestimated their knowledge, since there was no comparison in the performance at the real task in this study [LDR+21].

Makransky et al. [MBGM19] conducted a study with 105 undergraduate students, comparing the effectiveness of immersive VR (HMD), non-immersive desktop VR and printed manuals for delivering laboratory safety training. This training consisted of gaining factual, conceptual and procedural knowledge. The students had to pass a retention test immediately after the training with at least 70%, consisting of 18 question regarding the concepts and procedures, and two days later also perform the learned tasks in the real lab. In the immersive VR, the user was guided by a voice-over, explaining the simulation, tasks, questions and feedback on the tasks, additional visual information regarding safety labels was also given, showing on a virtual tablet. The tasks included treating acid spills and handling hazardous situations in a lab. One of the objectives was to learn the five safety hazards and then checking the environment for rule violation and safely handling those hazardous situations. In the end of the simulation, the participants filled an MC test with explanatory feedback in the VR. The real tasks in the lab, checking the environment for rule violations and acid spill on skin, were conducted in groups of three (all members from the same condition) under simulated stress and time pressure. The results show significantly higher enjoyments ratings in the immersive VR and desktop VR than in the printed media condition. These two groups also showed significantly higher increase in intrinsic motivation than the printed media condition. All groups show nearly identical mean scores on the immediate retention test. The immersive VR group shows significantly better results in the real task than the printed media condition, nevertheless, there is only partial evidence for the desktop VR performing better than the printed media. The main finding concerns the perceived enjoyment of the training, however, the novelty effect might contribute to it. Learner's emotional response to instruction can be positively influenced, especially when the learning activity is sufficiently controllable. The results show that VR simulations lead to higher enjoyment, which can positively influence the motivation to put effort in learning [MBGM19].

2.2.3 Summary

This section brings together the most important and relevant findings from the literature. Training using immersive VR...

- ... increases emotional engagement [FGA+20, LDR+21, MPGK15, SFLRS18].
- ... can enrich the learning process [PLS+21].
- ... leads to higher motivation and enjoyment [MBGM19].
- ... should always be guided and supervised by trainers [MPGK15, SRKS20, BMA+19, TPG+21].
- ... leads to more focus and better recall than non-immersive VR due to the ability to remember information relatively to the body [KPV19].
- ... leads to increased interest in VR after the scenario is practised [PLS+21].
- ... can make the training more efficient [PLS+21, SRKS20].
- ... is in the long term more effective than video training or desktop VR [LDR+21, MBGM19].
- ... is problematic in terms of haptic feedback, since it is not close enough to the real-world [PLS+21].
- ... leads to less error in the VR HMD group than those using desktop VR[KPV19].
- ... leads to shorter training time, higher self-confidence and easier recovery after errors than in real environments [PM08].
- ... mainly focuses on procedural skills [RMN21, GGBZ21, PLS+21].
- ... enables otherwise dangerous situations to be studied [FGA+18].
- ... makes a suitable tool for procedural training since it enables repeated training which can be varied and practised without the need for additional equipment [PLS+21].

Studies especially relevant to one of the three experiments of the case study are listed in tables for better overview of similarities, differences and measures. Table 2.1 lists studies focusing on the training of procedural skills in an industrial and safety context. They are relevant to the DigiLernSicher project (see section 3.1) in terms of type of trained skill, target group and learned task.

Relevant for DLS	Makransky et al. [MBGM19]	Górski et al. [GGBZ21]	Tanaka et al. [TPB+17]
Main objective	Examine the effectiveness of knowledge transfer (safety rules) using different types of VR training.	Find an optimal combination of interaction techniques and assess the suitability of VR simulations for the future training of electricians.	Assess the applicability of VR training as a supplement to the current trainings, to prepare the operators for working at critical infrastructure.
Conditions	Immersive VR (HMD) x desktop VR x printed manual	VR only, 3 modes of interaction and 3 modes of motion.	VR only, continuous development of the system with workers of the facility.
Task	Learn the terminology and 5 safety rules and apply them in a delayed real world scenario.	Learn and practise a 10-step procedure to prepare the system for the switch of a 110 / 15kV transformer.	Walk around the facility and check the equipment for errors.
Skill	Procedural	Procedural	Procedural
Participants	N = 105, engineering students	N = 30, electricians	N = 70, electricians
Measures	Pre-test (prior knowledge, motivation, self-efficacy), post-test (motivation, self-efficacy, perceived enjoyment), retention test (18 MC, real environment scenario).	Overall assessment of the application, perceived usefulness, measuring if the performance on a 2 weeks delayed test improved, number of hints, completion times.	Completion time, simulator sickness, overall usability and acceptance of the system.

Table 2.1: Summary of the characteristics and constructs measured in the studies relevant to the DigiLernSicher project.

Studies focusing on spatial orientation training, and way-finding in virtual environments are listed in table 2.2. These experiments show similarities in the trained task and context as the spatial orientation scenario from the XRTrain project (see section 3.2).

Spatial orientation	Feng et al. [FGA+20]	König et al. [KKC+21]	Schrom-Feiertag et al. [SFSS17]
Main objective	Create a VR based training for earthquake preparedness on the use case of hospital evacuation.	Investigate spatial navigation in virtual environments with different media.	Evaluate indoor guidance system in virtual environment using a way-finding task.
Conditions	VR HMD only	VR HMD x interactive map on desktop	VR CAVE only
Task	Correct behavioural response to a simulated earthquake, including building evacuation.	Absolute and relative orientation and pointing task after discovering a virtual city consisting of 213 unique buildings.	Find specified locations in the virtual environment, by using a map, following signs and asking avatars.
Skill	Procedural and spatial	Spatial	Spatial
Participants	N = 87, staff members and visitors	N = 22, university students and visitors	N = 22, volunteers
Measures	Familiarity with video games, knowledge acquisition (pre- and post-test), self-efficacy, ease of use, engagement.	Accuracy of relevant and cardinal orientation of landmarks, eye-tracking, spatial navigation strategies.	Eye-tracking, task-completion times, travelled distance and trajectory.

Table 2.2: Summary of the study characteristics and measured constructs in studies relevant to the spatial orientation scenario of the XRTrain project.

Studies describing VR experiments from the nursing and healthcare field, focusing on procedural and memory skills, are listed in table 2.3. These experiments show similarities in the trained task and context as the medical trolley scenario from the XRTrain project (see section 3.2).

Medical trolley	Bracq et al. [BMA+19]	Butt et al. [BKEE18]	Krokos et al. [KPV19]
Main objective	Examine the acceptability and usability of a new VR simulator for procedural skill training among scrub nurses.	Assess the usability and user reaction to, a game based VR simulation for urinary catheterization training.	Investigate the effect of spatial information representation on memorability and recall.
Conditions	VR HMD only	VR HMD x no-VR	VR HMD x desktop VR x printed list
Task	Select and place surgical instruments on a table accordingly to the protocol for craniotomy.	Practice urinary catheterization with an immediate feedback from an expert.	Remember a list of familiar faces and recall as many of them as possible, including their position.
Skill	Procedural	Procedural	Memory & spatial
Participants	N = 19, 13 expert nurses, 16 non-expert users	N = 20, undergraduate nursing students	N = 40, university students and staff
Measures	Personal innovativeness, familiarity with video games and VR, usability, workload (NASA TLX), presence, simulator sickness (SSQ), task-completion times, user acceptance, perceived usefulness of the training.	Usability (SUS), familiarity with video games, task-completion time, number of procedures completed in one hour.	Recall accuracy, number and position of error, familiarity with similar technology, preferred type of VR.

Table 2.3: Summary of the study characteristics and measured constructs in studies relevant to the medical trolley scenario of the XRTrain project.

2.2.4 Existing Recommendations for VR Training

According to Gavish et al. [GGW+11], the following suggestions should be incorporated into the guidelines for VR training:

- Observational learning should be properly integrated within the training protocol.
- The training of procedural skills can be enhanced by combining physical and cognitive fidelity.
- The scenario should include guidance aids in a controlled way.
- The task should be described clearly, in order to help the trainees to create a useful mental model of what needs to be done.

Further recommendations include:

- It is necessary to take enough time in order to familiarize users with the VR environment [MBGM19].
- The training should have clearly defined outcomes [RMN21].

2.3 Evaluation in the Virtual Reality Research

Virtual reality applications are still a relatively new and unexplored field without predefined evaluation norms. The evaluation of VR applications by user testing ensures appropriate development in terms of user comfort, experience and behaviour [Fuc17]. Various approaches and their combinations are used to assess the concepts described in section 2.1.

Akdere et al. [AJL21] describe suitable strategies for the evaluation and assessment of VR training. When evaluating a VR training using quantitative methods, participant's reaction to the experience and perception of the virtual environment should be measured. Self-report questionnaires are used to obtain characteristics such as feelings, motivation, presence, user experience or technology acceptance. In addition, it is important to assess the perception of the training and overall relevance of the training materials. Learning assessment, usually involving pre-, post- and retention-test, measures gained skills and knowledge. These measures are commonly assessed by using a set of questionnaires. This data is then analysed using corresponding statistical techniques [AJL21].

In qualitative approach, the phenomenon is studied from the participant's point of view in a structured way, which enables the findings to be generalized to a wider group of users. This approach is often used to study complex phenomena. When evaluating VR application, focus groups and interviews are especially helpful for understanding individual training experience. Qualitative research methods are particularly well suited for in-depth analysis including rich details, leading to a better understanding of VR training and its effects. Biometric approach is utilizing physiological and behavioural metrics. Behavioural biometrics can be used to measure affective states over time as a response to environment changes. Using biometric measures in the evaluation of VR application provides more direct feedback and helps to understand the experience of the participant beyond self-reported questionnaires. Common biometric methods used in VR evaluations are galvanic skin response, heart rate variability, facial movement detection and eye tracking. In summary, an evaluation using a combination of the described approaches is referred to as a mixed methods approach and provides a more comprehensive understanding of the studied phenomena. Also, this approach is being widely applied in research [AJL21].

Out of 60 studies reviewed by Renganayagalu et al. [RMN21], 33 applied between subject design in their experiments, 8 applied within subject design and 5 used mixed methods. Task performance is commonly evaluated after the training. The evaluation metrics can be divided into performance measures, self-reported measures and observations. Performance measures, such as task completion times, accuracy, correctly performed order of steps, error rate and timing were used frequently. Self-reported measures such as questionnaires and interviews assessing user experience were used in the user evaluation studies. The self-reported measures focus on measuring user experience, user satisfaction, system usability, perceived difficulty, immersion and presence [RMN21]. Comparing VR applications to traditional training methods is a viable method used by many researchers and was applied in the following studies: [MBGM19, LDR+21, MPS+20, KPV19, KKC+21, Car17, BC18, BKEE18].

Makransky et al. [MBGM19] compared three different groups, one using immersive VR, one using non-immersive desktop VR and another group using conventional printed media. He suggests a multi-tiered assessment framework for the safety training course. According to this framework, the objectives include increasing learner's motivation, gaining knowledge including facts and terminology and demonstrating these skills in a real setting. The differences in self-efficacy and knowledge gain in a pre-test, a post-test and a retention test were measured. The pre- and post-test using MC questions did not match the self reported knowledge gain. However, when using other measurement, significant differences among the groups were found. This led to the idea, that some effects can be only uncovered with certain methods of evaluation. Therefore, it is problematic to measure the learning effectivity of scenarios that are too dangerous to be trained in the real world [MBGM19].

Learning success in VR training depend on multiple factors. Schwarz et al. [SRKS20] conducted a field study focusing on assembly training in an automotive factory. They compared a group training in a virtual environment using HMDs with a control group working on a real car, being verbally guided by a trainer. The participants included 6 trainers and 15 novice workers. Both qualitative and quantitative data were collected, including observational data and event logging of the procedure. Mental load was assessed using the NASA TLX questionnaire. The group using virtual reality filled questionnaires regarding subjective learning success and perceived learning support, as well as user experience and presence questionnaires. Also, interviews with trainers were conducted. The training was conducted multiple times and the differences in the repetitions were measured [SRKS20]. Carruth [Car17] uses the following metrics: time required for task completion, accuracy, subjective assessment of the VR tool, usability, user experience, presence, mental load and simulator sickness. Training validation is done by testing the knowledge transfer by a task in a real world settings [Car17].

2.3.1 Summary

- User testing of VR applications ensures appropriate level of development in terms of user comfort, experience and behaviour [Fuc17].
- In the VR evaluation, combining quantitative and qualitative methods helps to get a more comprehensive understanding of the studied phenomena. This approach is common in the VR research [AJL21].
- Comparing VR applications to traditional training methods is a common method used in many relevant studies.
- Widely used evaluation metrics can be divided into the following categories: performance measures, self-reported measures and observations. Performance measure, include task completion times, task accuracy, error rate and timing. Self-reported measures such as questionnaires and interviews assessing user experience and are used frequently in user evaluation studies. The self-reported measures focus on measuring user experience, user satisfaction, system usability, perceived difficulty, immersion and presence [RMN21].
- Self-efficacy, assessing users' belief of how well they can perform a particular task [Dav89] is used in many studies focusing on learning with VR.
- It is important to assess simulator sickness, since it has negative impact on acceptance of the technology and the willingness to use it [SLEL+20].
- Technology acceptance among future users should be examined before the planned use. TAM and its extensions are commonly used in studies investigating the acceptance of VR systems [SLEL+20]. Positive user experience and usability have positive effects on technology acceptance, simulator sickness has a negative impact on technology acceptance [SLEL+20].
- It is important to include familiarity with technology [RMN21] and experience with VR in the questionnaires when assessing the background of participants, since these participants might be better at complex spatial tasks and tracking of multiple objects [MPS+20].

Table 2.4 offers a summary of metrics used in relevant studies described in the literature, which is also the basis for the metrics used in this work.

Metric	Description	Studies
Completion time	Time needed to perform the task.	[TPB+17, SFSS17, Car17, WRSF20, GGBZ21]
Task accuracy	The number of deviations from the defined procedure.	[KKC+21, WRSF20, Car17, KPV19]
Subjective mental load	NASA Task Load Index [HS88].	[BMA+19, SRKS20, Car17]
Presence	The subjective feeling of non-mediated experience of the virtual environment, measured by standardized questionnaires [SKHH19].	[BMA+19, LBR+15, KPV19, Car17, SFSS17, BKEE18, SLEL+20, BC18]
Usability	"Extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" [ISO10], measured by questionnaires and/or interviews.	[GGBZ21, BKEE18, TPB+17, BMA+19, Car17]
User experience	"Person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service" [ISO10], usually measured by standardized questionnaires.	[SRKS20, Car17, SLEL+20]
Technology affinity	User's attitude towards new technology.	[BMA+19]
Technology acceptance	Questionnaires based on the technology acceptance model (TAM) [Dav89] and consecutive work including TAM2 and TAM3 [VB08].	[FGA+20, MBGM19, BMA+19]
Cybersickness	The set of occurring symptoms, usually assessed in Simulator Sickness Questionnaire or its adaptations [KCDM19].	[BMA+19, SRKS20, SLEL+20, Car17]
Experience with VR and computer games	Participant's familiarity with VR and computer games, usually measured by a custom set of questions.	[BMA+19, FGA+20, LDR+21, KPV19, BKEE18]

Table 2.4: Metrics assessed in relevant studies.

CHAPTER 3

Approach

According to Baxter & Jack [BJ+08], the case study approach is suitable for answering "how" and "why" types of questions where contextual conditions and the studied phenomena are interconnected. Differences within and between cases embedded in similar context can be explored more efficiently when applying a multiple-case study approach [BJ+08]. Furthermore, this approach enables a broader exploration of the research questions while emphasizing the real-world context [EG07].

Eisenhardt & Grabner [EG07] recommend selecting cases that will help to illuminate and extend relationships and logic among different constructs. Such as combining cases which show similar patterns in some areas and contrasts in others. Moreover, the similarities and differences should be described clearly, for example, by using tables to summarize evidence for each theoretical construct and providing a visual summary in the form of diagrams. These tools help to visualize the insights emerging from the data [EG07]. In addition, when cases are chosen well, similar and contrasting results can be predicted across cases [BJ+08]. Qualitative approaches help to understand the individual experiences of the studied subjects, and the combination with quantitative questionnaire data helps to facilitate a better understanding of the problem. These data sources should be converged during the analysis and triangulated to confirm and validate findings [BJ+08]. Using a combination of the described approaches regarding data collection is being widely used in research and provides a better and a more holistic understanding of the phenomena [AJL21].

Based on the recommendations of Eisenhardt & Grabner [EG07], Baxter & Jack [BJ+08] and Akdere et al. [AJL21], the case study approach is suitable for our goal of establishing recommendations and guidelines for using single-user VR HMD in professional training. Empirical evidence from two projects, including three experiments with shared patterns and objectives, is utilized. This work combines quantitative and qualitative data from various sources, including objective performance measures, self-reported measures and observations. The data is collected in questionnaires, task performance measurements, observations, brainstorming sessions and interviews with experts and users.

The experiments for the case study were chosen based on their shared goals and context, which is described in detail in sections 3.1 and 3.2. Both projects focus on introducing virtual reality in professional training, but for different target groups. All described VR trainings have the goal of improving an existing learning paradigm (currently using printed materials, images and videos) with an interactive and more engaging way of learning. However, the usability of such training in the real-world setting must be further analysed. The study design for each of the experiments was developed considering the other experiments and the potential synergies with respect to individual constrains. Therefore, all scenarios are tested in a setting similar to the real-world future use case. The DigiLernSicher field study is conducted in vocational schools and training facilities. The XRTrain project, including the spatial orientation experiment and the medical trolley experiment, is conducted in a simulation hospital SIM Campus in Eisenerz, Austria. The main advantage of bringing these experiments together lies in the increased diversity of participants in terms of age, gender, level of experience with technology, expected technology affinity and background, which might have effect on the usability and acceptance of this technology.

The approach of iterative development including experts in workshops, mixed methods (qualitative and quantitative) in the experiments and the field study, help to examine the behavioural patterns of different groups and the underlying challenges for efficient and effective use of single-user VR training in the real-world context from the view of users with experience in the respective field. Additionally, during this process, data about further opportunities and challenges of single-user VR HMD training in terms of accessibility, learning outcomes, acceptance factors and motivation, as outlined in **RQ1** (see section 1.1.1), is collected, especially in qualitative interviews and questionnaires focusing on task-related measures. These findings then help to formulate guidelines for future VR trainings in the analysed domains, as described in **RQ2** (see section 1.1.1).

We use the same hardware devices in all three experiments, namely the Oculus Quest 2 head mounted display with controllers, same modes of navigation and interaction. For all scenarios, the teleport is the default mean of motion (besides walking) since this is the recommended way of movement, leading to reduced simulator sickness. [GGBZ21, TPG+21]. A summary of the similarities and differences characterizing the three experiments can be found in table 3.1.

3.1 DigiLernSicher

3.1.1 Goals of the Project

DigiLernSicher is an Austrian research project conducted together with AVL List GmbH, Mindconsole GmbH, AIT Austrian institute of Technology GmbH, WIFI Steiermark, Energie Steiermark AG and Landesberufsschule Voitsberg, funded by Arbeiterkammer

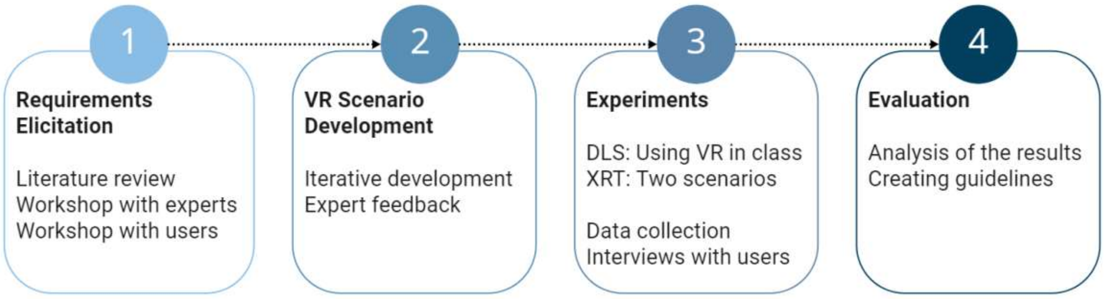

Figure 3.1: A visualization of the project steps. The only differences are in the experiment step, where DigiLernSicher (DLS) uses different setup than XRTrain (XRT).

Steiermark. This project aims to develop and evaluate VR scenarios for electrician training at AVL GmbH and WIFI Steiermark, and examine its feasibility and prospects for future use. Energie Steiermark AG and Landesberufsschule Voitsberg also used the training scenario in their education of electrician apprentices.

3.1.2 Project Structure & Background

The project starts with requirement elicitation. In this process, similar projects described in the literature are collected and analysed, and then, two workshops with experts and future users are held. In the next step, a functional prototype is developed together with Mindconsole GmbH using an iterative process. In each iteration, possible changes are discussed with experts and researchers. This system is then tested with electrician apprentices in a field study. Educational institutions and companies are involved in this phase and use VR training in their classes for electrician apprentices. During this phase, data is collected in the form of questionnaires and interviews. Then the data is evaluated, measuring user experience, presence, mental load, self-efficacy of conveyed knowledge and cybersickness. In the interviews (see table A.5), questions regarding training experience, possible improvements, perception of added value to education, way of integration and possible roles of trainers are asked. The four steps of the project timeline are visualized in figure 3.1.

The tasks and situations for possible scenarios were identified based on the work accident statistics in Austria in the years 2016-2020 and data collected during two design-fiction workshops with future users and experts. Eisenhardt & Grabner [EG07] suggest, that input from highly knowledgable informants who have different points of view on the phenomena is the key to minimize bias [EG07] and Tanaka et al. [TPG+21] recommend discussion in focus groups involving experts as a great source of information when developing training scenarios. Therefore, the scenario was developed together with the team of Mindconsole GmbH in an iterative process, supported by a group of six experts from the field of electrical engineering and education of electrician apprentices. Also, electricians, instructors and safety specialists were asked to participate in the development process.

The first workshop was focusing on trainers and teachers who will use the technology in their classes. The initial ideas were discussed with experts who already work in this field for many years and have experience in educating electrician apprentices.

The second workshop focused on the apprentices. Its main objective was planning and discussing possible scenarios and selecting learning content for the VR training from the learners' perspective. Another important goal of this workshop was to assess user acceptance and its challenges, focusing on the advantages and disadvantages the participants see in the use of this technology. During the workshop, the participants also had the opportunity to try a game using a virtual reality HMD. Nine apprentices of electronics and electrical engineering currently learning at AVL GmbH took part in the workshop. Four of them were in their second year of education, five were in their third, second to last, year.

3.1.3 Findings from the Workshops

One of the main topics mentioned in both workshops is the current state of knowledge transfer, especially the content regarding safety information. The participants discussed which ways of learning are preferable and in their view most efficient, and what can be done to improve the current state of education. It was discussed which specific scenarios or situations for conveying safety-relevant content could be implemented in a VR environment. First, common mistakes and problematic situations in electrical engineering have been discussed and listed. Of particular interest are situations with a high-risk potential or high complexity. Further, current approaches were discussed and compared with the future possibilities of VR. All suggestions were noted on post-its and weighted by relevance the future users assigned to them.

Common materials to teach about electricity and its risks are worksheets and textbooks. Sometimes also videos and images are used. Currently, the education consists of 50 percent practical classes and 50 percent frontal teaching. The apprentices have admitted that they often learn with YouTube videos at home, since they find them more understandable than lessons. In general, the apprentices wished for more practical and tangible ways of learning integrated in the practical classes.

The main topic suggested in both workshops is the difficulty to teach and practice the "Five Safety Rules", which are causing trouble to both students and teachers, since a mistake can lead to severe consequences. In the current training programme, this topic is taught right at the beginning of the four-year apprenticeship. However, these rules are not being practically trained in a real-world context and there are insufficient opportunities to practice them. This topic is also relevant for the final apprenticeship exam. Also, working with high voltage is becoming more relevant with the use of electric vehicles. Other suggested training scenarios are laying cables in a house or a flat, working on switch-boxes, working on power lines, and simulation of damaged wires and incorrectly connected or damaged sockets. In general, all the listed scenarios involve high hazard potential, and training in virtual reality can make the learning experience much safer and more realistic than training in a lab. As discussed during the workshops, using VR can make the training independent of the location and specialized equipment of the training facility. The VR devices are portable and can be effortlessly taken to any training location. It also enables simulating work with expensive materials and measuring devices. Also, the training can be done independently at own pace, and the number of repetitions is not limited. It would be also possible to record, visualize and gamify one's progress and review it afterwards to introduce other kinds of feedback that can be done individually or in groups as an additional exercise.

It is of significant disadvantage that precise technical activities (e.g. soldering, setting up electronic circuits) are likely to be difficult to implement or train in a VR environment due to limited haptic feedback and accuracy. It was also critically noted that training in a VR environment adds to the amount of screen time. In addition, VR can be used for a rather short time, as symptoms of fatigue appear afterwards. Finally, it was suggested that training in VR can only be a good addition and cannot replace real practice.

Further steps (three and four) are described in the following chapters of this work. In particular, the field study in section 4.1 and the evaluation in section 5.1.

3.2 XRTrain

The XRTrain project is an Austrian project funded by the Arbeiterkammer, conducted together with Mindconsole GmbH, AIT Austrian institute of Technology GmbH and WIFI Steiermark. In this project, VR training for the education and training of emergency services in the health and safety sector is developed and tested.

3.2.1 Goals of the Project

The main goal of the project is to develop and evaluate training scenarios for healthcare workers and emergency response forces with respect to possible limitations given by group diversity. The question of potential disadvantages for certain user groups from the perspective of diversity research has not yet been addressed adequately. We aim to investigate, if there are certain disadvantages for certain user groups (e.g. visual impairments, age groups, previous experience with similar technologies) and create guidelines applicable when using VR technologies that help overcome these difficulties. Therefore, we focus on cybersickness vulnerability, prior knowledge of digital technologies and training content, eyesight and other socio-demographic characteristic. The training environment should have minimal disadvantage potential, be inclusive and easy to use to all users. An important point is the subjective experience of users and their feeling and confidence while training with the system. In addition, we examine which activities and skills can be supported by VR and how this training is perceived by the users.

3.2.2 Project Structure

In the beginning, literature regarding VR training for first responder organizations (e.g., physicians, paramedics, health care workers, police officers, firefighters) is collected and analysed. Multi-stakeholder workshop with experts on education and incident response training from the Austrian Red Cross, experts on emergency, crisis and disaster simulation from the SIM Campus, and future users is conducted. Second, based on the gathered requirements, the scenario descriptions are formulated and discussed with experts who have experience working as trainers in the medical field. Third, the scenarios are implemented and tested with medical personnel. The experiments were conducted in January 2021 at the SIM Campus, Eisenerz, Austria. The project steps are very similar to the DigiLernSicher project, depicted in figure 3.1.

3.2.3 Findings from the Workshop

Training and education of emergency response forces are very complex due to the necessary interaction among many people and multiple organizations. Possible applications are trainings for tunnel accidents, terrorist attacks and natural disasters, where new training approaches to large scale exercises are required. With VR, such scenarios can be practised regardless of time and location in various settings and complexity, enabling multiple groups to prepare for the same scenario independently and still gain the same knowledge. For example, groups from different location can prepare separately, and then have a more advanced and efficient training together. Nowadays, the organization of such drills are quite laborious, thus through the use of VR the organizational complexity, so as the costs can be decreased.

Health care professionals are faced with procedural activities on a daily basis. Virtual reality environment enables to train in a standardized way and offer more room to self-lead learning and on-demand training. Another advantage is that such environments allow mistakes to be made without endangering the physical safety of the trainees and other people or damage machines involved in the training. Errors can also be analysed afterwards, and the scenario can be repeatedly trained with slight modifications in order to train active thinking and dealing with different disruptive factors or complications accordingly. Additionally, training formats using simulation or digital media have gained profoundly in importance, due to the restrictions resulting from the COVID-19 pandemic.

Two scenarios were defined as a result of a workshop with stakeholders and experts. One scenario focuses on the acquisition of spatial orientation skills. The scenario simulates an evacuation of a hospital, to test if VR is a viable way of training for such a situation. The second scenario focuses on the preparatory steps of a medical procedure. Equipment for an intubation is laid on a medical trolley. The description of how the study is conducted is described in section 4.2.1.The following steps of the study are described in other chapters of this work. The experiments are described in detail in sections 4.2.1 and 4.2.2, the results are described in sections 5.2.1 and 5.2.2.

	DigiLernSicher	Spatial Scenario	Medical Trolley
Project objectives	Develop a training scenario which can be used for electrician training on various institutions.	Develop a scenario of an evacuation, examine, if VR training is a viable way of preparing for such emergency compared to traditional methods.	Develop a scenario for practising preparing a medical trolley for an intubation and compare it with traditional learning methods.
Guidelines focus	The training must be usable at various institutions educating apprentices.	The trainings must be inclusive for a wide variety of users.	The trainings must be inclusive for a wide variety of users.
Type of skill	Procedural	Spatial Orientation	Procedural
Task in VR	Checking electric installations in a flat accordingly to a standardized protocol.	Following a marked path through a building, remembering the path.	Preparing instruments for intubation with visual hints viewed on the medical trolley.
Real world task	VR only, however this exact procedure is relevant for the final apprenticeship exam	Finding this exact way in the real building without hints.	Preparing instruments for intubation on the same trolley in a real world, without hints.
VR Device	Oculus Quest 2	Oculus Quest 2	Oculus Quest 2
Training location	Vocational schools and training centres	Simulation hospital	Simulation hospital
Repetition	Participants compete the training scenario multiple times.	All participants complete this scenario once.	All participants complete this scenario once.
Training time	Each participant can practice the VR scenario as long as necessary.	The participants train in VR for 8 minutes.	The participants train in VR for 8 minutes.
Target group	Electrician apprentices	Nurses in training	Nurses in training
Participants	Mostly male	Mostly female	Mostly female
Age groups	Teens	Adults	Adults
Technology experience	High	Low	Low
Experiment design	Field study	Between-subjects	Between-subjects
Groups	VR only	VR x Non-VR	VR x Non-VR
Measured constructs	Technology affinity [WAF19], presence (IPQ [Sch03]), user experience (UEQ-S [SHT17]), mental load (NASA TLX [HS88]), VRNQ [KCDM19]), self-efficacy, see section 4.1.5	Additionally to the measures of DLS, time per task, number of deviations from route, number of hints and hesitation are measured, see section 4.2.1	Additionally to the measures of DLS, time per task, number of errors are measured, see section 4.2.2

Table 3.1: Comparison of the similarities and differences among three experiments included in the case study.

CHAPTER 4

Case Study

4.1 DigiLernSicher

4.1.1 Study Design

A field study is conducted to investigate the acceptance, usability and presence concerning future use and establish guidelines for integrating VR training into curricula. Both qualitative and quantitative methods are used to get more in-depth insights [Roh14].

The study can be divided into three phases (see figure 4.1). In the beginning, a kick-off workshop is conducted. The purpose of this event is to inform all participants and trainers about the timeline of the study, ensure that everyone knows how to use the VR HMD and how to interact in the scenario, and collect demographic data and contact information for further communication. The second phase consists of the VR use and the second questionnaire. Participants are once reminded (via e-mail) to fill out this questionnaire, however, no other interventions are made. It is up to the facility and the responsible trainers, how they decide to integrate the VR training. The study is closed with a third questionnaire and a qualitative semi-structured interview. Details of the first, second and third questionnaire are described in table 4.2. The VR simulation was created by the team of Mindconsole GmbH[1] who gave permission to use the image material in this work.

Figure 4.1: An overview of the DigiLernSicher field study timeline and structure.

[1] https://mindconsole.net/

Figure 4.2: The setup of the HMD with the QR-Code.

4.1.2 Procedure

The study starts with a kick-off workshop where the project, its timeline, motivation and goals are introduced to the participants. Each participant gets an ID to use when starting the scenario and filling out the questionnaires, and a tutorial on how to use the Oculus Quest 2 and how to interact within the scenario. Each participant gets the opportunity to practice the scenario and ask questions. During this workshop, all participants fill out the first questionnaire. Thereafter, the VR headsets are available at the facility for two to three weeks. There is a QR-code linking to the second questionnaire at the HMD as in figure 4.2. During this time period, the participants are once reminded via e-mail to take time to practice the scenario and fill out the second questionnaire. How the VR is used in the class is let upon the trainers. At the facility of AVL List GmbH, the VR training is done during the breaks on a voluntary basis. The Landesberufsschule Voitsberg and Energie Steiermark AG are using the training as a part of the regular classes. After the given time period has passed, the participants fill out the third questionnaire and some of them take part in a semi-structured interview via phone call.

4.1.3 Scenario

The DigiLernSicher scenario depicts a flat with possibly damaged electric installations. The goal is to check the installations accordingly to a protocol (see figure 4.6) and make sure that basic protection accordingly to DIN VDE 0100 is given. This is a common procedure, however, difficult to practice in the training facility. Therefore, it was recommended by trainers and experts to simulate this case in the VR. There are 15 different variables representing the electric installations. Ten sockets at four different places, or the fuse box itself might be damaged or wrongly installed. They are either not working, visibly burned or wrongly installed. Also, the following devices might be damaged: stand lamp, table lamp, television, toaster. Every time a scenario is started, these variables are generated randomly. When the scenario is started, the user sees the

Figure 4.3: Hallway, the starting point of the scenario (left) and the living room of the virtual flat (right).

Figure 4.4: Voltage tester, test lamp and two locks (left) and the fuse box in the hallway (right).

hallway of the flat (see figure 4.3). A yellow circle is shown in front of the door, to draw user's attention. When the user approaches the door, they can see an input device and written instructions (see figure 4.5). After typing the ID and clicking the green button, a new scenario with randomly generated variables is started.

The flat consists of three rooms: a hallway, a bedroom and a living room with a kitchen (see figure 4.3). The user can move around freely, either by walking or teleporting. On an imaginary belt, there are several measuring devices within the reach of user's hands: a voltage tester, a test lamp and two locks that can be used for securing the fuses and the fuse box (see figure 4.4). Then the user can decide how and in which order to check the basic protection of the flat. When everything relevant is checked, the user goes back to the door and fills out the protocol and receives feedback (see figure 4.6).

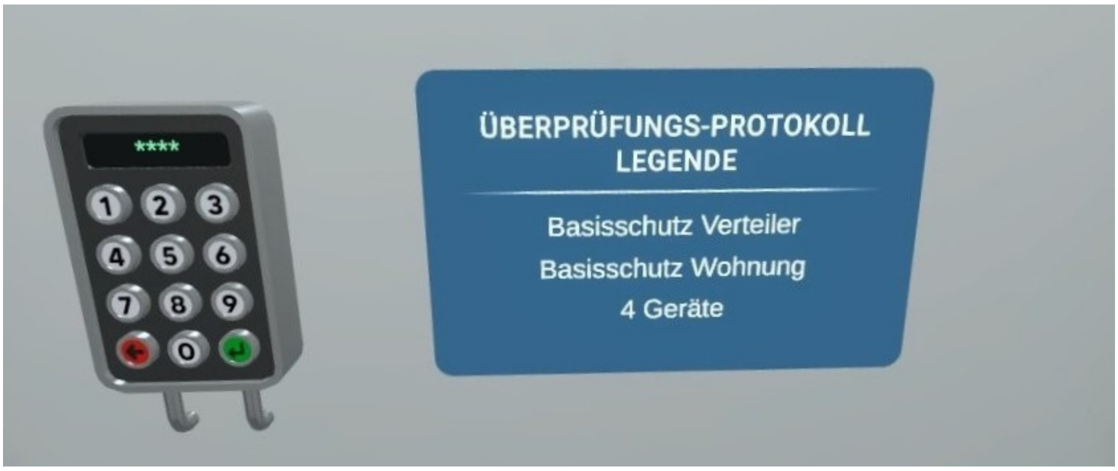

Figure 4.5: Entering code when starting the scenario and a brief description of the task: basic protection fuse box, basic protection flat, 4 devices.

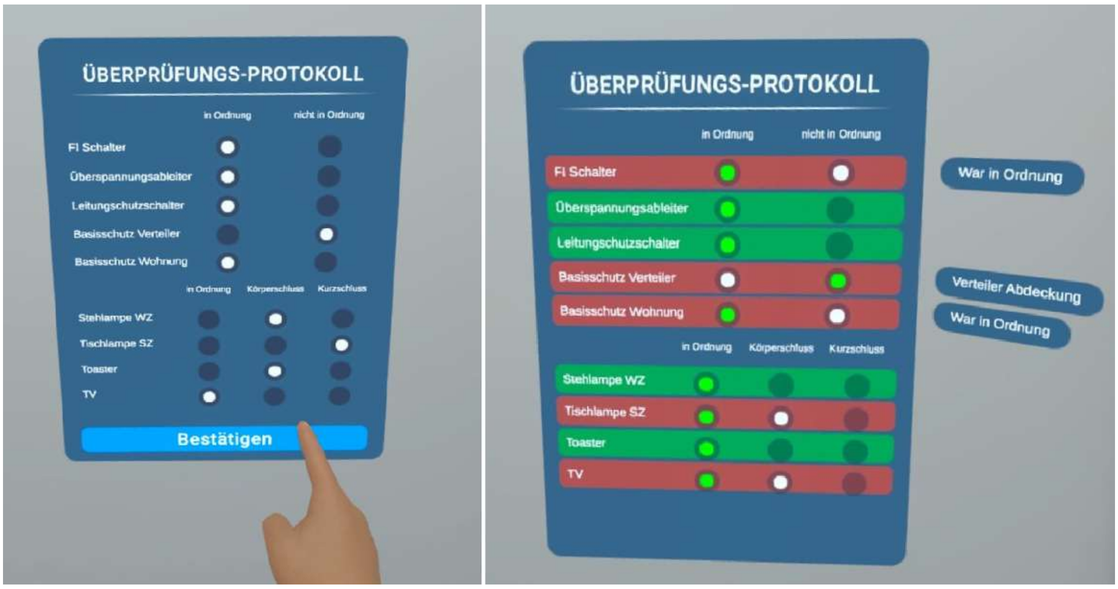

Figure 4.6: The protocol at the end of the scenario, without and with feedback.

4.1.4 Participants

There are 109 apprentices participating in the study, coming from different project partners, described in detail in table 4.1. The project partners, AVL List GmbH, Landesberufsschule Voitsberg and Energie Steiermark AG are interested in using similar training systems in the future and therefore asked their apprentices to take part in the study. All participants and in the case of underage participants, also their parents, were informed and declared consent with the study.

Group	AVL	LBS Voitsberg	E-STMK	All
Number	n = 15	n= 79	n=15	n = 109
Age				
M	16.87	18.47	18.13	18.20
SD	1.36	2.00	2.90	2.15
Min	15	15	16	15
Max	19	27	27	27
Sex (in %)				
Female	13.3	3.8	0	4.6
Male	86.7	96.2	100	95.4

Table 4.1: Characteristics of the participants in the DigiLernSicher project.

4.1.5 Data and Analysis

Data is collected in three questionnaires and a semi-structured interview. The measures for this experiment were selected based on the literature review (see section 2.3). Related studies and their measurements are briefly described in table 2.1. The selected questionnaires are either being used frequently in studies with similar structure or are recommended for evaluation of similar use cases (see table 2.4).

Questionnaire	Content
First	Demographic information, see table A.1 Affinity for Technology Interaction - Short [WAF19]
Second	Igroup Presence Questionnaire (IPQ) [Sch03, SKHH19] NASA TLX for assessing mental load [HS88]
Third	Virtual Reality Neuroscience Questionnaire (VRNQ) [KCDM19] User Experience Questionnaire - Short (UEQ-S) [SHT17] TAM questionnaire [Dav89, SLEL+20] A.4 Self-efficacy questionnaire of quality of learning A.3

Table 4.2: Questionnaires used in the DigiLernSicher study.

Interviews
The interviews are conducted to specifically question the aspects of acceptance and practical feasibility of the VR training. Secondly, interviews are also well suited to deepen and supplement the quantitative data collected in the questionnaires [AJL21]. The interviews are conducted via phone call (due to COVID-19 restrictions), taking between 10 and 20 minutes per participant, and consist of 13 questions which are listed in table A.5. Participants are invited to participate in the interviews during the kick-off workshop. In total, 30 participants were interviewed, the results are described in section 5.1.3. Interviews were analysed accordingly to the qualitative content analysis by Mayring [May00]. Their results are described in section 5.1.3.

4.2 XRTrain

4.2.1 Spatial Orientation Scenario

Study Design

The goal of this study is to investigate the usability, accessibility, acceptance and presence of a scenario focusing on orientation, which could be used for future evacuation training. In order to compare the learning outcomes between two training methods, one using a virtual reality scenario and the other using printed materials, the participants are randomly assigned to these two conditions. The printed media condition was selected because it is a common practice, and because it enables independent practice, no matter the time and location [BSEL+22]. Analogical approach in comparing groups with and without VR is used in the following studies: [MBGM19, LDR+21, MPS+20, KPV19, KKC+21, Car17, BC18, BKEE18], which are described closely in section 2.2. The participants from both groups are taking part in the experiment alternately to avoid sequence effects. Both groups have the same amount of time to prepare for the task. After the training time has passed, the participant performs the task in the real environment. Time, number of errors and further performance indicators are measured, as described in section 4.2.1.

Procedure

At the beginning of the experiment, each participant gives their informed consent, is registered, receives a unique ID and is reminded not to talk about the experience with others. All participants are brought to a waiting room near the entrance, so that they do not see the building's interior. In the waiting room, they are informed about the timeline of the study and its goals. This experiment is conducted in parallel with the medical trolley scenario described in section 4.2.2, in order to efficiently use the available resources and shorten the waiting time for the participants. Each participant is assigned to the VR group in one experiment and to the no-VR group in the other. The participants are picked up one after the other from the waiting room and brought to the training room (room number 018), where they prepare for the task. They either learn by using a printed map (see figure 4.7) or by practising the route in the VR simulation. Before starting the timer, the participants are instructed on how to interact within the VR scenario, how to move around and how to adjust the glasses, so that they fit comfortably and the vision is clear. While being instructed, the participants are asked to teleport themselves, but to not leave the start room and speak loudly in case of having any issues with the system. When signalizing they are ready to start, the timer with 8 minutes is started, they can leave the start room and practice. Then the participants can practice freely for 8 minutes, the scenario is designed to be practised several times during this time.

Before the task in the real environment starts, the participant gets a smartwatch (Garmin fēnix 6 Pro) measuring their heartbeat and a pair of Tobii[2] eye-tracking glasses which are calibrated for each participant. One observer is following the participant. When starting the task in the real environment, the participant is once again reminded of what the goal is and that they should not interact with the observer in other ways than asking for the next room number in the case, they forget the route. The observer is measuring the time, tracking the route with a map-protocol, and can give a hint by saying the next room number if asked. Given hints, so as long moments of hesitation are noted. The observer is not interacting with the participant. The participants finish the route in another waiting room so that they do not influence the participants who are still waiting to start. In this room, they fill out the questionnaire, which consist of the measures described in table 4.4. An interview with selected participants is then conducted in a separate room. All interview questions are listed in German and English in table A.6.

Task

The participants are asked to remember a route within the building which consists of 5 rooms (016, 004, 102, 112, 125), rooms starting with 0 are located on the ground floor, and those starting with 1 are located on the first floor. However, they are not instructed on how to remember the route. The goal is to visit the rooms in the given order without branches or shortcuts, following the dashed line as in the map or the VR simulation. The participants are asked to walk as they would usually, not running or walking overly fast. None of the participants visited or have seen the building before. The room numbers written on the doors in the VR simulation and on the map are identical to those in the real world, of which all participants are reminded. Participants in both groups have 8 minutes to prepare for the task. The time for the task itself is unlimited.

Scenario

The spatial orientation scenario shows a model of the building of the SIM Campus [3] in Eisenerz, Styria, Austria. A former hospital, which was transformed into a simulation hospital in 2019. This facility is nowadays used for training of medical personnel, but can be still turned into fully functional hospital if necessary.

[2]www.tobiipro.com
[3]www.simcampus.eu

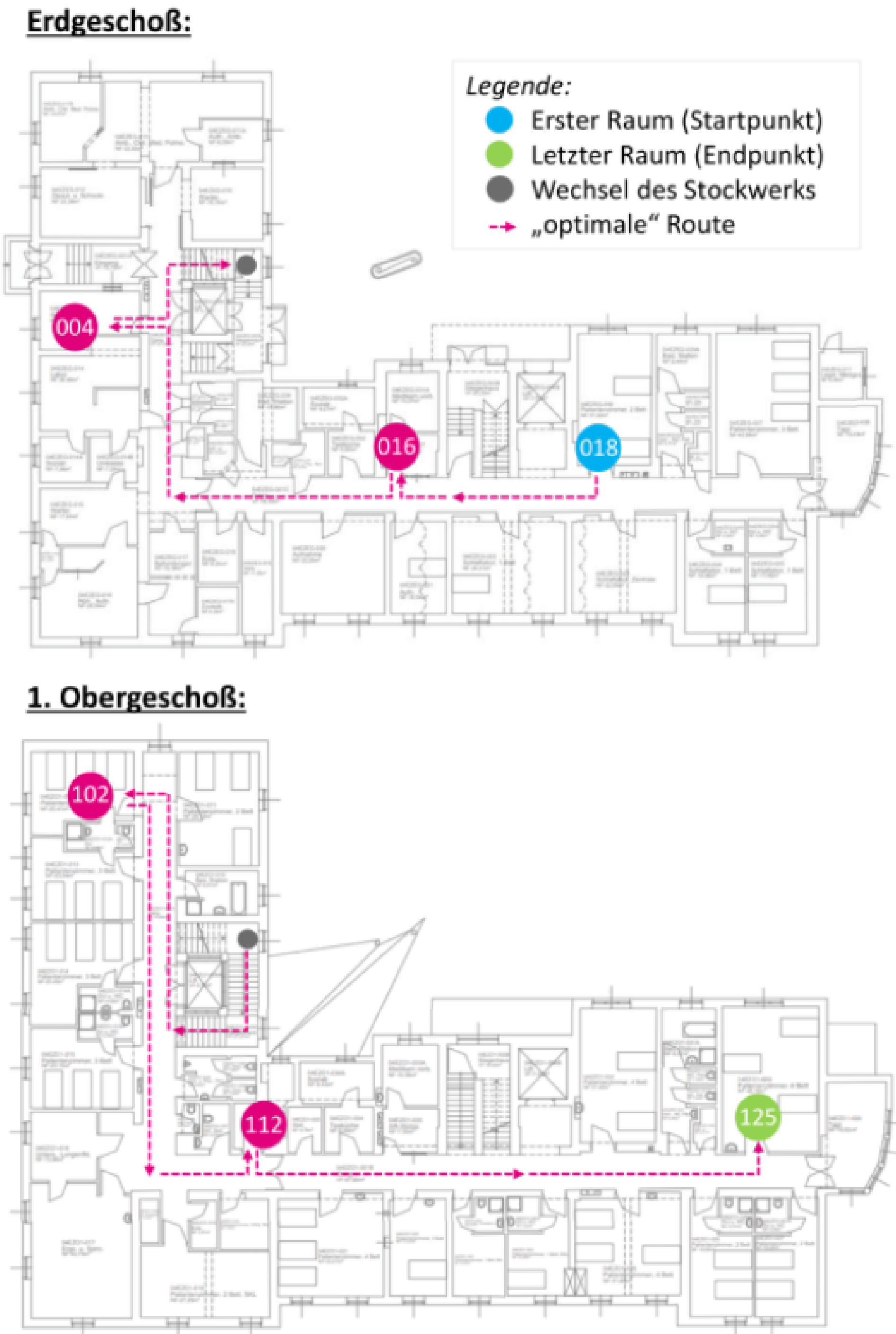

Figure 4.7: The map of the building, which was used to prepare the control group for the task.

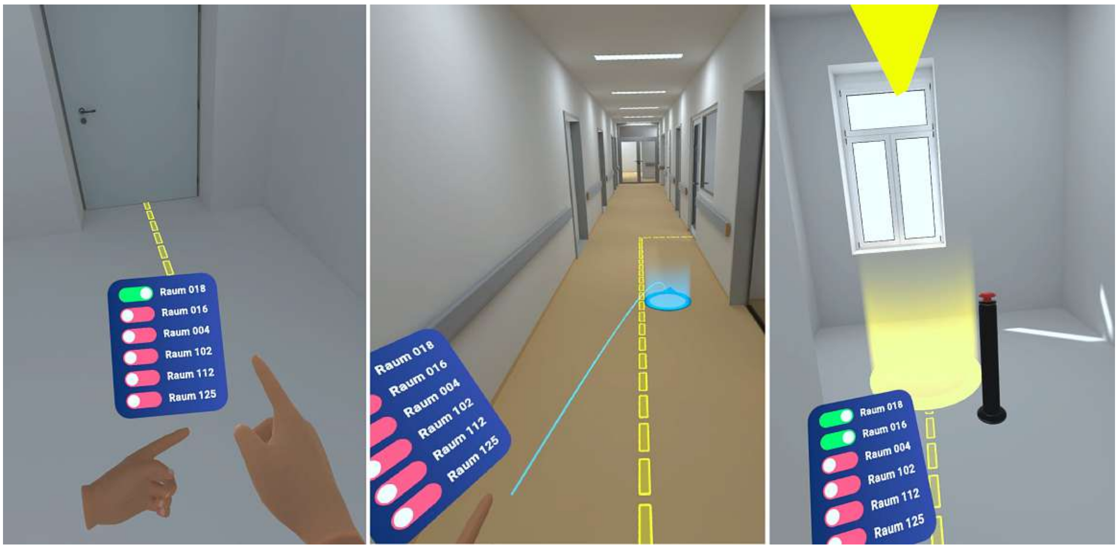

Figure 4.8: The view of the user when starting the scenario (left), user's view of the hallway with pointing teleport (middle), and a room to be marked as visited (right).

Figure 4.9: The path leading to the first room (016) in the VR (left) and the real hallway (right).

At the start of the VR scenario, the user is located in the room 018, on the ground floor, the same room as the real start room. The details of the building such as flooring, doors, windows, numbers on doors and room descriptions are kept as close to reality as possible in the VR scenario, however, the rooms were not furnished in the VR. At the position of the left controller, a list of the five rooms the participant has to visit is placed (see figure 4.8). Green and red tics signalize if the rooms were visited already. In order to move in the scenario, the user can either walk around or use teleport by pointing with the right controller, pressing a button and then releasing it. The user sees a yellow dashed line on the floor which is leading the way from one room to another (see figure 4.9). When a room from the list is entered, the user can see a yellow circle on the floor and a buzzer next to it (see figure 4.8). When the user enters the circle and presses the buzzer, the tick at this room number turns green. The buzzer in the last room says "restart" and teleports the user to the starting room and restarts the scenario. The user can also turn off and on the yellow dashed line marking the way by pressing the joystick on the right controller.

Participants

Nursing students from FH Sankt Pölten and Akademie für Gesundheitsberufe Wien were offered participation in the study. Those interested in participating registered via an online form. In total, 41 participated in the study. Characteristics of the participants are listed in table 4.3.

	VR	noVR	Total
Number	n = 20	n = 21	n = 41
Age			
M	33.10	34.05	33.58
SD	8.99	9.65	9.22
Min	21	21	21
Max	51	52	52
Sex (in %)			
Female	85.00	95.24	87.81
Male	15.00	4.76	12.19

Table 4.3: Characteristics of the participants in the spatial orientation scenario.

Data and Analysis

The measures for this experiment were selected based on the literature review and the goals of the study. These measures are recommended and commonly used in similar experiments. An overview of related studies are described in table 2.2) and their measures are listed in table 2.4.

Measures	Used Questionnaires
Experience-related measures	User Experience Questionnaire - Short (UEQ-S) [SHT17] Virtual Reality Neuroscience Questionnaire (VRNQ) [KCDM19] Igroup Presence Questionnaire (IPQ) [Sch03, SKHH19] Adapted questions from the TAM VR [Dav89, SLEL+20] listed in table A.4
Additional demographic measures	Affinity for Technology Interaction - Short (ATI-S) [WAF19] Experience with VR (see table A.1) Experience with computer games (see table A.1) Self-assessment of the sense of orientation

x

Table 4.4: Measures assessed in the questionnaire which was filled immediately after the task in the spatial orientation scenario.

Variable	Description
Time per task	Time between leaving the start room (018) and reaching the end room (125).
Number of deviations	Number of cases where the participant left the foreseen route, missed a room, or entered a wrong room. These deviations were further categorized by their severity.
Number of hints	Number of hints asked by the participant.
Number of hesitation	Number of times the participant stopped for a significant amount of time and waited before the next action.

Table 4.5: Dependent variables for measuring task performance in the spatial orientation scenario.

Observation

During the tasks in the real world, one observer recorded the participants movements in the building by drawing their route onto a paper map of the building and noted the variables described in table 4.5. These observations help to analyse the variables described in table 4.5.

Interview

Seven participants who trained with the VR simulation were interviewed. These participants were selected based on the map protocols. In order to have a wide representation of answers, participants who performed above average in terms of time, errors and hints, participants who had difficulties during the task or already reported problems during the VR training and participants who performed on average were interviewed. All questions are listed in table A.6. Interviews were analysed accordingly to the qualitative content analysis by Mayring [May00]. Their results are described in section 5.2.4.

4.2.2 Medical Trolley Scenario

Study Design

The goal of this study is to examine the differences between two training methods, one using virtual reality scenario and the other printed materials, by applying a between-subject design with random allocation of participants to these two training conditions. The printed media condition was selected based on the following criteria: first, the method is nowadays common practice, second, it enables independent practice, no matter the time and location [BSEL+22]. To better understand the attitude of future users towards the system and get relevant insights regarding applicability from people working in the medical field, nurses in training and students of nursing profession were invited to participate in the study.

Procedure

At the beginning of the study, each participant gives their informed consent, is registered, receives a unique ID, and is reminded not to talk about the experience with others. Then, the participant is brought to a waiting room near the entrance. In the waiting room, everyone is informed about the procedure, timeline and goal of the study.

This experiment is conducted in parallel with the spatial orientation scenario described in 4.2.1, in order to efficiently use the available resources and shorten the waiting time for the participants. Each participant is assigned to the VR group in one experiment and to the no-VR group in the other.

The participants wait until their ID number is called, then an assistant brings them to the room where they prepare for the task. A researcher explains the task in detail, and if necessary, answers further questions. Participants from the VR group are instructed how to use and adjust the VR headset and how to interact in the scenario. They are reminded to speak up if any problems occur. When they confirm, that everything is clear and the headset fits comfortably, the timer is started, and they can start the medical trolley VR training. Participants from the no-VR group receive two A4 pages with instruction, one depicting a written list of all instruments that need to be put on the medical trolley and the other with images of all these instruments and the correct layout (see figure 4.10). Both groups have 8 minutes to prepare for the task. When the time is up, the assistant brings the participant to the room with the real trolley. In this room, the researcher repeats the steps of the task and answers questions if necessary. Then the participant performs the task and the researcher protocols it. The time is not limited, the participant determines when the task is finished. Afterwards, the participant fills out questionnaires in a separate room, and some participants are also asked to take part in an interview. All measured variables are described in section 4.2.2.

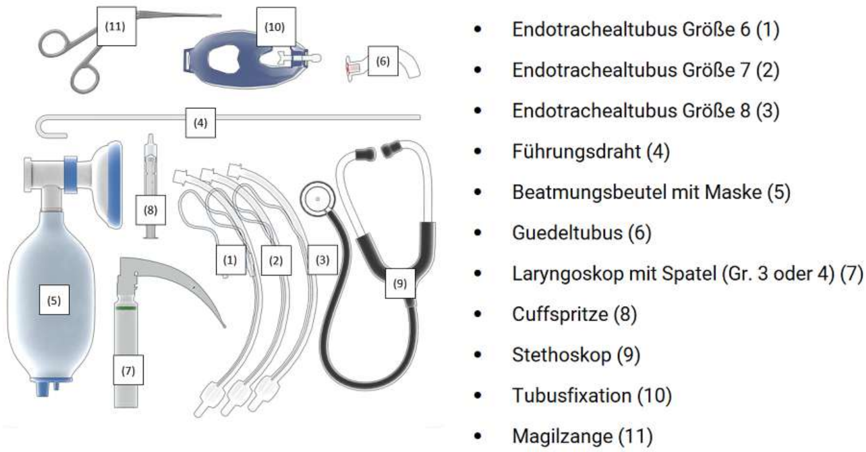

Figure 4.10: The printed training material of the no-VR group. Translation: Endotracheal tube size 6 (1), endotracheal tube size 7 (2), endotracheal tube size 8 (3), guide wire (4), resuscitation bag with mask (5), Guedel tube (6), laryngoscope with spatula (size 3 or 4) (7), cuff syringe (8), stethoscope (9), tube fixation (10), magil forceps (11).

Task

The participants are asked to remember 11 medical instruments for intubation and their position on the medical trolley. These instruments are initially located in the drawers of the trolley. The trolley used in the experiment and the layout of the instruments are depicted in figure 4.11. In order to prepare for the task, participants use either printed materials or train in a VR simulation.

Scenario

The VR scenario consists of one room equipped with the medical trolley (see figure 4.11), which was modelled accordingly to the real trolley used in the experiment. The objects in the simulation are placed in the drawers in the same way as in the VR simulation. Next to the trolley, three buttons with the following labels are located: stencil, check and reset. A stencil on the top of the trolley shows all instruments for intubation and their position. The oxygen mask is located in a basket on the left side, all other instruments are found in the drawers. The user looks for the items, grabs them by using the controllers, and places them on the stencil. A counter in the height of users' eyes is showing how many items are placed already. The user can press the grey "check" button to see if the items are placed correctly. The button will light up red when there is at least one mistake, or green when everything is correct. The "stencil" button turns the background stencil of the layout on the top of the trolley on and off. The user can practice without the stencil to better prepare for the real task. The "reset" button cleans the top of the trolley, and puts all objects back to their original places. The training process is depicted in figure 4.12.

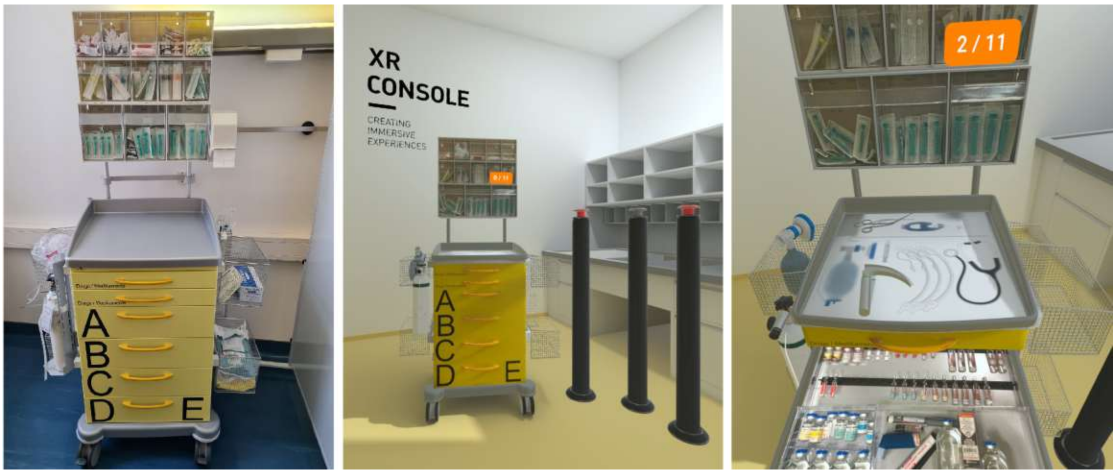

Figure 4.11: The real medical trolley (left), the virtual trolley and the whole setup with buttons (middle), and a detailed picture of the top of the trolley (right).

Figure 4.12: Participant training in VR (left), participant's view of the trolley (middle), the buttons next to the trolley (right).

Participants

The study was conducted with 41 participants, students of nursing schools (n=34), medical students (n=3) and nursing school teachers (n=4). Nursing students of FH Sankt Pölten and Akademie für Gesundheitsberufe Wien were offered participation in the study. Those interested in participating in the study registered via an online form. Characteristics of the participants are listed in table 4.6

	VR	noVR	Total
Number	n = 21	n = 20	n = 41
Age			
M	32.95	32.58	32.53
SD	14.71	11.26	9.37
Min	21	21	21
Max	52	51	52
Sex (in %)			
Female	95.24	90	92.68
Male	4.76	10	7.3

Table 4.6: Characteristics of the participants in the medical trolley scenario.

Data and Analysis

The measures for this experiment were selected based on the literature review and the goals of the study. These measures are recommended and commonly used in similar experiments. An overview of related studies can be found in table 2.3, their measures are listed in table 2.4. All participants filled out a questionnaire immediately after finishing the task.

Variable	Description
Time per task	Time needed to perform the task. The participant decides when the task is done.
Number of errors	Number of cases in which too few, too many or wrong objects were placed on the area of the medical trolley at the end of the task.
Number of hints	Number of questions that imply uncertainty on the part. In these cases, the person guiding the study did not provide any information about the correct processing of the task.

Table 4.7: Dependent variables for measuring task performance in the medical trolley scenario.

Measures	Used Questionnaires
Experience-related measures	User Experience Questionnaire - Short (UEQ-S) [SHT17] Virtual Reality Neuroscience Questionnaire (VRNQ) [KCDM19] Igroup Presence Questionnaire (IPQ) [Sch03, SKHH19] Adapted question from the TAM VR [Dav89, SLEL+20] listed in table A.4
Additional demographic measures	Affinity for Technology Interaction - Short (ATI-S) [WAF19] Experience with VR (see table A.1) Experience with computer games (see table A.1) Experience in preparing intubations Experience with medical trolleys

Table 4.8: Measures assessed in the questionnaire which was filled out immediately after the task in the medical trolley scenario.

Observation
During the task, a researcher is measuring the time needed for the task completion, number of hints asked and number of errors, by filling a protocol. After the task is finished, the top of the medical trolley is photographed for documentation and further analysis.

Interviews
After finishing the medical trolley task, 9 participants who trained in VR were asked to participate in a semi-structured interview. These participants were selected based on their performance during the task. Three participants who performed extremely well, three participants who experienced difficulties and three participants who performed on average were invited, to equally represent different outcomes. All questions are listed in table A.6. Interviews were analysed accordingly to the qualitative content analysis by Mayring [May00]. Their results are described in section 5.2.4.

CHAPTER 5

Results

5.1 DigiLernSicher

After an overview of the demographic data of the participants, this section presents the qualitative and quantitative results of the case study.

5.1.1 Demographic Data

A total of 109 apprentices took part in the field study of the DigiLernSicher project in cooperation with three partner organizations, which could be recruited via the WIFI Styria network. Table 5.1 provides an overview of the number of participants from each organization, as well as their year of training and the professional background. In order to also question the suitability of the learning approach for the different phases of the apprenticeship, participants from all apprenticeship years were involved in the field study.

Training facility	Participants	Year of study	Specialization
AVL	15	13 in the 1st year, 2 in the 3rd year	Electrical, machining, mechanical and automotive technicians
Landesberufsschule Voitsberg	78	43 in the 4th year, the others from 1st-3rd year	Electrical engineering and electronics apprentices
Energie Steiermark	16	all participants in the 2nd year	Apprentices in the fields of electrical engineering, plant engineering and industrial engineering

Table 5.1: Summary of the number of apprentices taking part in the DigiLernSicher study, their affiliation, year of study and specialization.

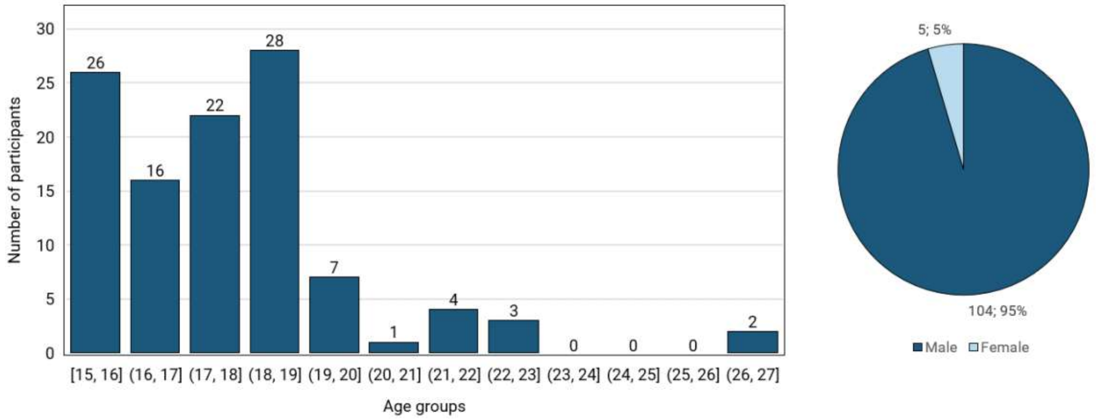

Figure 5.1: Distribution of the participants' age (left) and gender (right) in the DigiLern-Sicher field study (N = 109).

Age & Gender

The participants were mostly male. There were only 5 female apprentices taking part in the study (see figure 5.1). The age distribution of the study participants in the field study strongly reflects the apprenticeship years of the participants (see figure 5.1). Only 10 participants were older than 20 years. The youngest participant was 16 years old, the oldest 27. On average, the study participants were 18.2 years old (N=109, SD = 3.4).

Degree of Education

With regard to the highest level of school education they have completed to date, the group of participants who are currently completing their apprenticeship after completing compulsory schooling (81%) was naturally the largest (see figure 5.2). In addition, 15% of the participants had already completed an apprenticeship or technical school, individual participants (4%) also had a high school diploma (N=108).

Affinity for Technology Interaction

According to the ATI-S scale [WAF19], the participants in the field study showed a medium to high affinity for technology (see figure 5.2). The mean value on the scale with possible values from 1 to 6 is 4.25 (N=108, SD = 0.84). The answers grouped by the questionnaire components are visualized in figure 5.3. When asked about their experience with virtual or augmented reality (see figure 5.4), 50 out of 108 participants stated that they had no experience with these technologies. Another 32 participants indicated that they had little experience with these technologies. And only 7 participants felt that they had a lot of experience using these technologies. When asked about the frequency of using computer games, more than half of the participants stated that they played computer games at least 1-3 times a month and 38 of the participants use computer games less than 1-3 times a month.

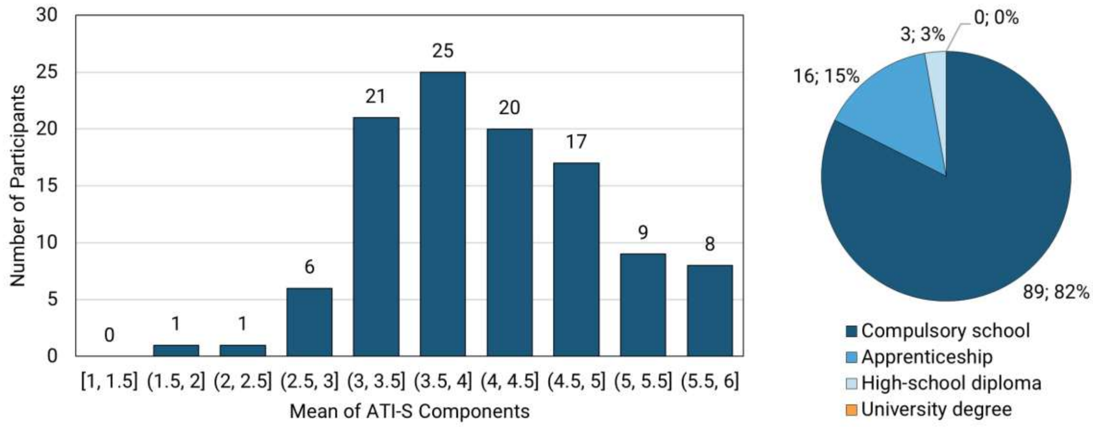

Figure 5.2: Histogram of means of ATI-S scale in the DigiLernSicher scenario (N = 108).

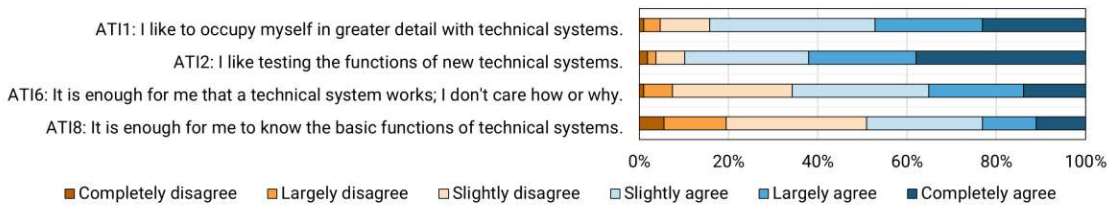

Figure 5.3: Distribution of the answers in the DigiLernSicher sceario listed by the ATI-S components (N = 108).

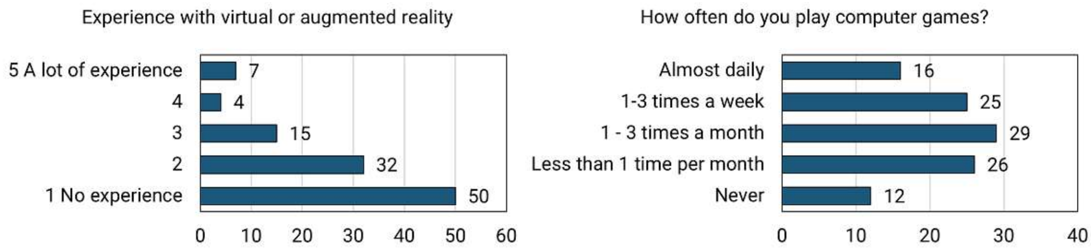

Figure 5.4: Previous experience with VR and computer games in the DigiLernSicher scenario (N = 108).

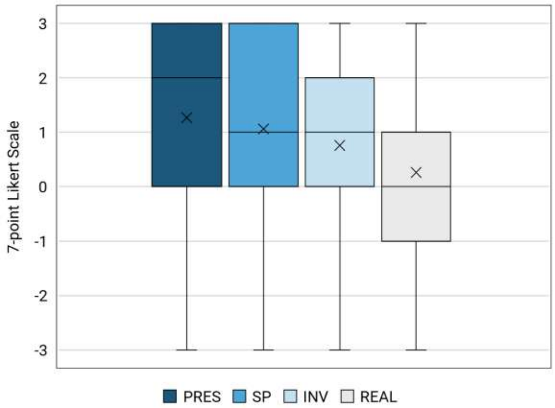

Figure 5.5: The means of the IPQ scale components in the DigiLernSicher scenario (N=111).

5.1.2 Questionnaires

Presence

The standardized IPQ (igroup Presence Questionnaire) [Sch03] was used to measure presence. This was part of the questionnaire that should be filled out after each use of the system. With regard to the presence perceived by the participants in the VR training environment, the DigiLernSicher solution consistently shows high values (see figure 5.5). Comparing the individual subcomponents of the IPQ scale shows a high general presence (PRES, question: "In the computer generated world, I had a sense of "being there"). The quality of the spatial environment (SP) of the tested VR scenario was rated high. Also above average, but less, compared to the general and spatial presence are the values of involvement (INV), e.g. the feeling of being completely immersed in the virtual world and forgetting the real world. The tested training scenario performs somewhat average in terms of the realisticness of the scenario (REAL). On this point, there seem to be aspects in which the virtual environment of DigiLernSicher differs noticeably from a real training environment. These points are discussed in the interviews in section 5.1.3.

User Experience

Several instruments were used to survey user experience and technology acceptance as central aspects for evaluating the implementation quality of the VR-based training solution, as well as important indicators for the future willingness of apprentices to use such training. While several pragmatic and hedonic user experience dimensions of the overall solution were collected using the User Experience Questionnaire Short (UEQ-S) [SHT17], the Virtual Reality Neuroscience Questionnaire (VRNQ) [KCDM19] is used to specifically collect the perceived quality of the implemented VR learning scenario. In addition, further questions on important aspects of technology acceptance were given, based on TAM-3 questionnaire by Davis et al. [Dav89] and Sagnier et al. [SLEL+20].

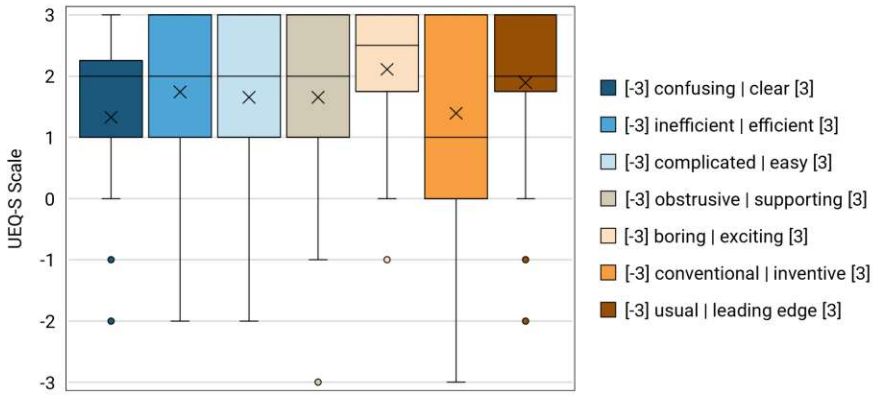

Figure 5.6: Results of the User Experience Questionnaire (short) in the DigiLernSicher scenario (N=46).

User Experience Questionnaire - Short

When looking at the results of user experience (see figure 5.6), which were collected in the final questionnaire using the UEQ-S scale, positive results are shown on average for all user experience dimensions. The training solution implemented in DigiLernSicher is perceived as interesting, exciting and new. Also for the dimensions of clarity, efficiency, simplicity, originality and the feeling that the system supports you in operation, there are very positive results on average for all participants.

Virtual Reality Neuroscience Questionnaire

The results of the implementation quality as perceived by the participants (see tables 5.2 and 5.3), which were collected using the Virtual Reality Neuroscience Questionnaires (VRNQ) are on average very positive for all participants (see figure 5.7). The degree of immersion experienced was rated as neutral or high to extremely high by almost all participants. Satisfaction with the VR experience was rated even better, with almost all feedback ranging from high to extremely high. The quality of the VR technology overall, i.e. including the hardware, was also perceived as high to extremely high by most participants. In comparison to the other components, the options high, neutral and low are selected more frequently for the graphics quality. This, as well as the frequent choice of the “neutral” option for the component, indicates that some of the participants involved would have liked an even more realistic implementation of the VR-based training scenario with regard to the graphic quality of the solution. With regard to motion sickness, the results of the VRNQ scale show that the majority of the participants did not experience any intense feelings of nausea, dizziness, fatigue or instability in the VR environment. Overall, about one-third of the participants reported experiencing moderate, mild, or very mild feelings of motion sickness during or after the training. A comparison of the individual components of the scale shows that only the aspect of disorientation was rated somewhat worse on average (although still clearly in the positive range) than the other components. This indicates that individual participants had problems operating the system with regard to this aspect.

	What is the level of immersion you experienced?	What was your level of enjoyment of the VR experience?	How was the quality of the graphics?	How was the quality of the VR technology overall (i.e. hardware and peripherals)?
AVG	4.72	5.48	4.94	5.35
SD	1.15	1.3	1.37	0.97

Table 5.2: Virtual Reality Neuroscience Questionnaire - User Experience, DigiLernSicher, Scale 1 to 7, (N = 46).

	Did you experience nausea?	Did you experience disorientation?	Did you experience dizziness?	Did you experience fatigue?	Did you experience instability?
AVG	5.91	5.41	6.07	6	5.65
SD	1.63	1.45	1.24	1.43	1.61

Table 5.3: Virtual Reality Neuroscience Questionnaire - VR Induced Symptoms and Effects, DigiLernSicher, Scale 1 to 7 (N = 46).

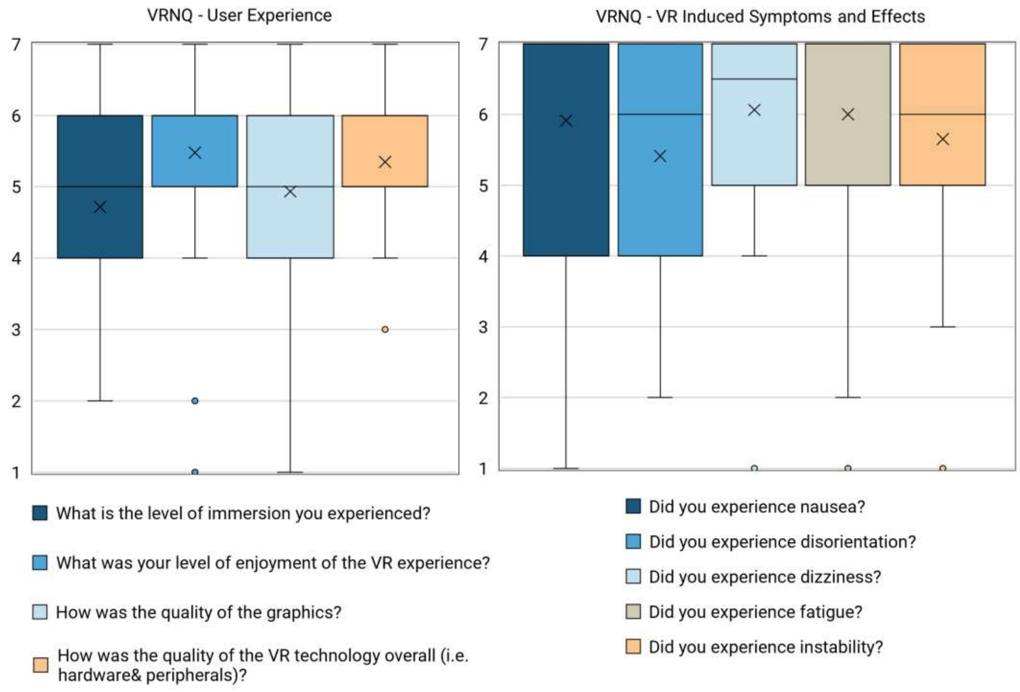

Figure 5.7: Results of the Virtual Reality Neuroscience Questionnaire, DigiLernSicher, Likert Scale 1 to 7, (N = 46).

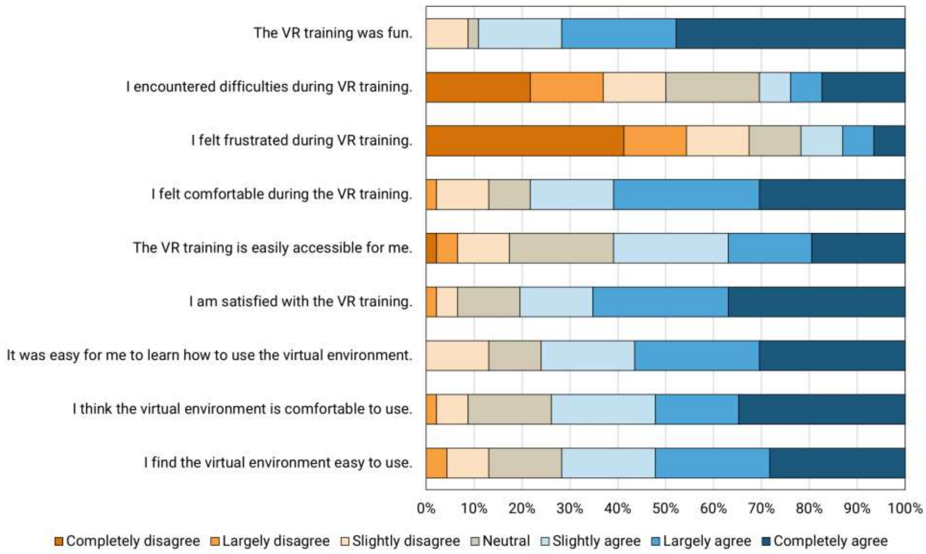

Figure 5.8: The results of the adapted technology acceptance questionnaire in DigiLern-Sicher. Likert Scale 1 to 7, (N=46).

Technology Acceptance

With regard to the acceptance of the evaluated training solution, the results of the field study show consistently positive values (see figure 5.8). The virtual environment was found to be easy and comfortable to use by the majority of the participants. The participants found it easy to learn how to use the training system, and most of the participants were generally satisfied with the DigiLernSicher solution. The fact that the VR-based training was rated as less accessible by some participants is probably due to the conditions of the field study, in which no immediate subsequent use of the system beyond the test phase was planned. Furthermore, the quantitative results also show that the participants felt very comfortable using the system on average: for the questions about possible frustration or possible difficulties in using it, the results show only low values. Using the system has caused little frustration or difficulty. The results on technology acceptance also clearly show that fun is a key user experience factor for apprentices.

Self-efficacy of Quality of Learning

For perceived quality of learning, a questionnaire developed by AIT was used (see table A.3). In total, 50 participants fully answered this questionnaire. With reference to whether the participants think they can apply the content learned in the VR training in practice (see figure 5.9), 33 out of 50 participants responded that this was definitely or very definitely the case, 12 out of 50 participants were somewhat confident about this aspect, and only 5 participants stated that they were not so confident or not at all confident that they could put in practice the content conveyed via the VR training.

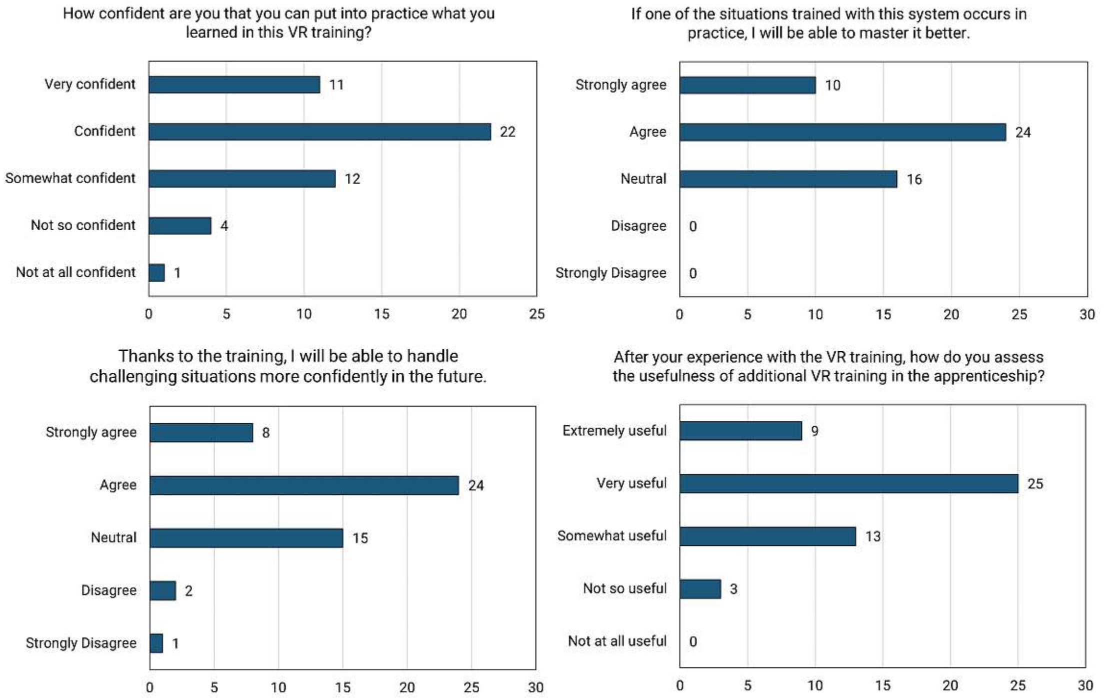

Figure 5.9: The self-efficacy of quality of learning and usefulness of the training, (N=50).

5.1.3 Interviews

All 15 apprentices from AVL, 12 apprentices from LBS Voitsberg and 3 apprentices from E-STMK took part in the interviews, resulting in a total of 30 interviews.

Question 1: What did you find positive about the training, what worked well?

The majority of participants rated the training positively. Only one person didn't like the training - *"not really my thing"*[1] (p. 2). The most significant category, addressed by 20 participants, was user experience in general (see figure 5.10), pointing out that everything worked well without any technical problems. The participants liked the scenario graphics and setup. The comfort of the HMD, control and interaction and high degree of authenticity were perceived positively by 12 participants. The perceived quality of learning was important to 12 participants. Even though, not all the participants were doing an electrician apprenticeship, almost all the apprentices of different specialization said, that they found it fascinating to gain interdisciplinary hands-on knowledge in a safe way, which they could not do otherwise.

There were two main statements for why they found the content of the scenario interesting.

[1] "nicht so meins"

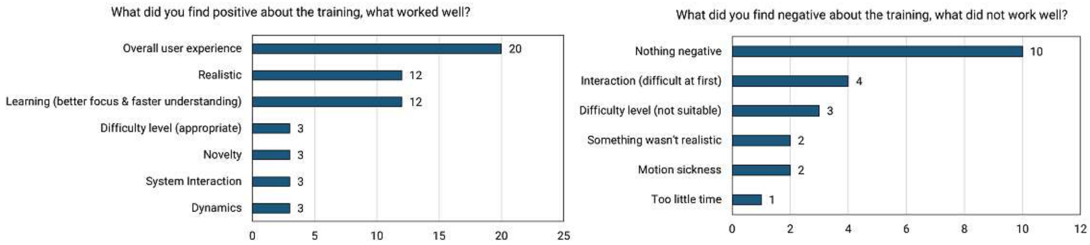

Figure 5.10: First interview question: "What did you find positive about the training, what worked well?" (left) and second question: "What did you find negative, what did not work well?" (right), DigiLernSicher scenario (N=30).

The students who did an electrician apprenticeship said, they liked trying and practising tasks they learn about only in theory. The students who did other apprenticeships pointed out, that some content was completely unknown to them and thus complicated. However, they enjoyed getting insights into other specializations and new situations. Different levels of difficulty would have been helpful. Also, the whole training approach in general was appreciated: *"You can learn better that way, today's youth can deal better with such a system and the Internet than with lots of slips of paper, we are more used to that. That something like this is developed at all is great!"*[2] (p. 10).

Question 2: What did you find negative, what did not work well?

When asked openly about things that did not work well with the VR-based training, 10 participants said that they could not name any negative experiences (see figure 5.10). Four participants stated that they had certain problems interacting with the system, whereby this feedback relates almost exclusively to the initial use of the system and in particular to the possibility of teleporting: *"Only when teleporting, there it was confusing when you're suddenly standing right in front of a wall"*[3] (p. 25). Three participants commented that the level of difficulty of the training was either too advanced or too low. Two participants commented that the realism of the VR-based scenario was not high enough because objects would not fall to the ground (p. 8) and the measuring device, for example, did not offer the possibility of *"switching between different units"*[4] (p. 19). Two participants noted that dizziness was a problem when operating the training, especially after a longer operation of *"about 15-30 minutes"*[5] (p. 21). With regard to the implementation of the field study, one participant noted that the time to try out the system during the breaks was not enough to get a good picture of the VR-based training

[2] "Dass man so in dem Sinne besser lernen kann, heutige Jugend kann besser mit so einem System und dem Internet umgehen, als mit vielen Zetteln, wir sind das mehr gewohnt. Dass man sowas überhaupt entwickelt, ist super!"

[3] "Einzig beim Teleportieren, da war es verwirrend, wenn man plötzlich direkt vor einer Wand gestanden ist.“

[4] "unterschiedlichen Einheiten umzuschalten“

[5] "etwa 15-30 Minuten“

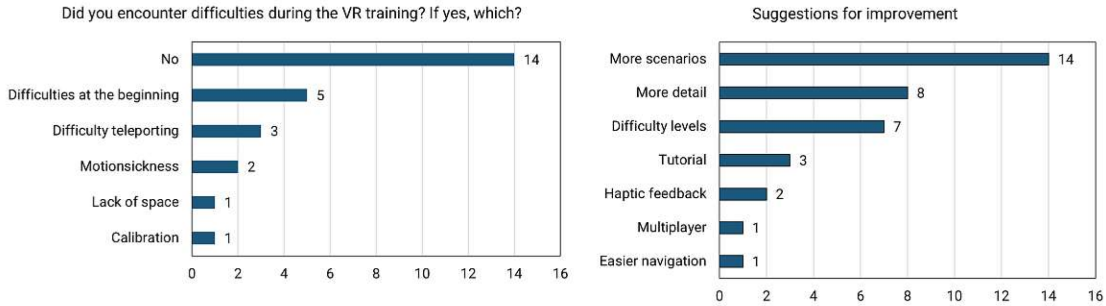

Figure 5.11: Third interview question: "Did you have any difficulties during the VR training? If yes, which? " (left) and the fifth interview question: "Do you have any suggestions for improvement regarding VR training?" (right) , DigiLernSicher scenario (N=30).

(p. 5). One short participant complained about not being able to see all the object properly: *"Because I am so short, I didn't see the fuse box and the checklist properly. This made it extremely difficult for me. I didn't get dizzy either, although I often have problems with dizziness."*[6] (p. 14). This problem was caused by not calibrating the VR headset for each participant separately, because the height of the objects was set dynamically.

Question 3: Did you have any difficulties during the VR training? If yes, which?

When asked more specifically about difficulties that arose during the use of the VR-based training (see figure 5.11), 14 participants said that there were no problems at all. Five mentioned difficulties that were perceived during the first operation of the training, e.g. when operating the controller (p. 9, 27), the orientation in the VR scenario (p. 2) or the operation of the measuring device (p. 7). Three participants noted that the teleporting was unusual, e.g. *"...that you suddenly found yourself in a wall or in the fuse box"*[7] (p. 17). Two participants noted that they experienced dizziness during or after operating the scenario, and noted that the usage area for the VR-based scenario in the classroom was too small (p. 14), or that they had difficulties setting up the play area (Guardian) (p. 13).

Question 4: Were you satisfied with the VR training? Why? Why not?

When asked about general satisfaction, 88% of the participants stated that they were very satisfied or satisfied with the VR-based training. Only one participant (p. 2) stated

[6] "Weil ich so klein war, dass ich den Schaltkasten und die Checkliste nicht gescheit gesehen habe, das hat es für mix extrem schwierig gemacht. Auch schwindelig ist mir nicht geworden; obwohl ich sonst schon oft Problem mit Schwindel habe"

[7] „... dass man auf einmal in der Wand oder im Sicherungskasten steht“

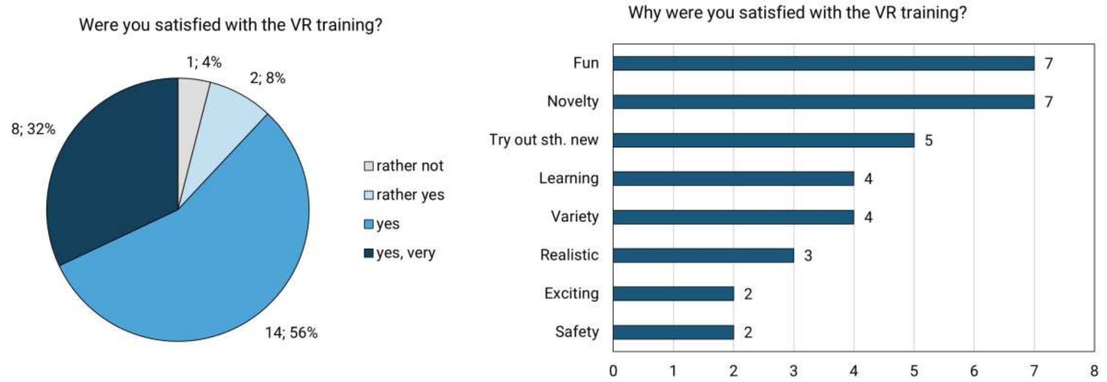

Figure 5.12: Fourth interview question: "Were you satisfied with the VR training? Why? Why not?", DigiLernSicher scenario (N=30).

that they were not satisfied with the tested training because they generally did not like the interaction in virtual reality environments. Overall, the VR training was welcomed as an interesting innovation in the education.

The participants primarily mentioned the fun of interacting within the system and the novelty of the training approach as the reasons for their satisfaction with the VR-based training (7 participants each). Several participants also emphasized that it was good to be able to apply basic learning content in VR (4 participants). The potential of the training to contribute to increased learning success was also emphasized by four participants. In this context, one participant said that they can imagine this approach in particular *"for preparing for the final apprenticeship exam, because you have to master exactly these topics well"*[8] (p. 27). The realism of the VR-based learning scenarios (p. 6, 9) was also given as a reason for satisfaction with the tested training approach. One participant emphasized that it was good *"to be able to practice such topics in VR first and only then in reality"* - which was *"much safer that way"*[9] (p. 9). One participant pointed out the importance of movement similarity in VR and real world, which helped to learn better: *"It's good that you make similar movements with the controlers as you do in real life: that's why you learn it quickly"*[10] (p. 9). The users also reported high presence. They found the HMD comfortable to wear and mentioned they have almost forgotten they were wearing it (p. 13).

[8]"Ich kann mir sowas für die Vorbereitung zur Lehrabschlussprüfung vorstellen, weil man da genau diese Themen gut beherrschen muss."

[9]"solche Themen zuerst in der VR üben zu können und dann erst in Realität" - dies sei "so auch viel sicherer"

[10]"Gut ist, dass man mit den Sticks ähnliche Bewegenungen macht, die man auch sonst in der Realtität auch macht: deswegen lernt man das Schnell"

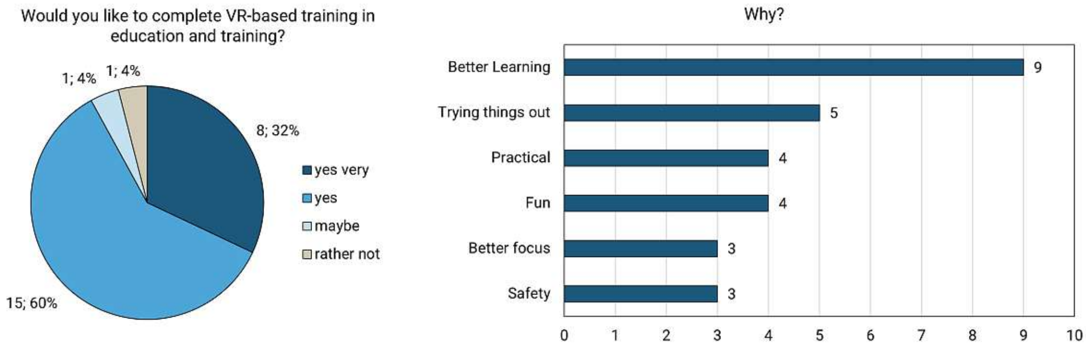

Figure 5.13: Sixth interview question: "Would you like to complete VR-based training in education and training? Why?", DigiLernSicher scenario (N=30).

Question 5: Do you have any suggestions for improvement regarding VR training?

When asked about possibilities and wishes for improving the VR-based training system (see figure 5.11), the interviewed apprentices mentioned in particular the implementation of further training scenarios (14 participants). In the area of electrical engineering, topics such as installations in the sanitary area or in the area of agriculture were mentioned, because different standards apply. The connection of motors was suggested as an interesting area of application. Scenarios such as the operation of CNC machines or training in the field of mechanics were also suggested by the apprentices who are not doing an apprenticeship in electrical engineering. Several participants also suggested that the existing training scenario could be made more realistic by adding more details (8 participants). In this context, it was said, to design the light switches to be functional as well, or to integrate further possible errors into the scenario. The measuring device must also be made more realistic, for example by being able to set it to different types of tension (p. 16). Another improvement suggestion that was mentioned several times (7 participants) concerns the implementation of different levels of difficulty for the individual learning scenarios. Three participants called for the implementation of simple, e.g. video-based tutorials that explain interaction in the VR environment in particular (p. 6, 22, 23).

Question 6: Would you like to complete VR-based training in education and training? Why?

When asked whether they would like to use VR-based training during their training (see figure 5.13), over 90% of the participants answered positively. Only two participants answered this question with “maybe” (p. 27) or “rather not” (p. 2) and argued that the usual training was already sufficient.

Nine participants gave a better learning success as a reason why they would like to have a VR-based training system like that of DigiLernSicher available in the apprenticeship:

"... because I would have understood many things more easily. One remembers them better than if only taught theoretically"[11] (p. 10); *"... because this exercise is very instructive, and I can concentrate better than in normal lessons"*[12] (p. 4). It was also positively emphasized by several participants that you can try out scenarios in the VR environment that cannot be practised in class, but are important for the final apprenticeship exam (5 participants): *"in the training workshop you only do "little things" like soldering – but (here) you can see how the things are connected, that you light up a lamp and see immediately if everything is in order, that's what you cannot practice otherwise"*[13] (p. 10). Learning with the VR training enables to see complex relationships and understand the bigger picture. Otherwise, practical knowledge is often isolated.

The practical relevance and the fun while using the system were given by four participants as reasons why they would like to use a system like DigiLernSicher in teaching. In this context, three participants mentioned that *"you can't break anything"*[14] (p. 17), and also the safety when practising: *"I also think it's good that you can try things out before you do them in reality."*[15] (p. 12).

Question 7: In your opinion, how could VR training be integrated into training? (Would it make sense to use the VR glasses in the training centre, at school or at home?)

During the interviews, the participants expressed a clear preference that VR-based training should at least be integrated as part of the lessons in the vocational school (22 participants). In any case, several participants felt that VR training also had to have a fixed place in the timetable (6 participants), or that VR training could be well anchored as part of laboratory lessons (6 participants). The aim of this training should be to deepen the theoretical knowledge that has just been taught (6 participants): *"I would do it by scheduling the theory lessons beforehand, for example two weeks; and then practice with VR for maybe a week; (so that) you can then directly apply what you have learned in theory; then you remember things much better"*[16] (p. 10). Five participants also expressed the desire to have the learning content of the VR-based training available at home.

[11]"... weil ich viele Sachen so leichter verstanden hätte. (Man) merkt sie sich besser, als wenn man sie nur theoretisch erzählt bekommt"

[12]"... weil dieses Üben sehr lehrreich ist und ich mich dabei besser konzentrieren kann, als beim normalen Unterricht"

[13]"in der Lehrwerkstätte macht man nur „kleine Dinge" wie zu Löten – aber wie die Dinge zusammenhängen, dass man eine Lampe ansteckt und gleich sieht, ob alles in Ordnung ist, das kann man sonst nicht üben"

[14]"man kann nichts kaputt machen"

[15]"Ich finde es auch gut, dass man da Dinge ausprobieren kann, bevor man wirklich in die Realität geht."

[16]"Ich würde es so machen, dass man vorher die Theoriestunden ansetzt, zum Beispiel zwei Wochen; und dann die Übung mit der VR, vielleicht eine Woche lang; (sodass) man dann auch direkt anwenden kann, was man in der Theorie gelernt hat; dann merkt man sich die Sachen sicher viel besser"

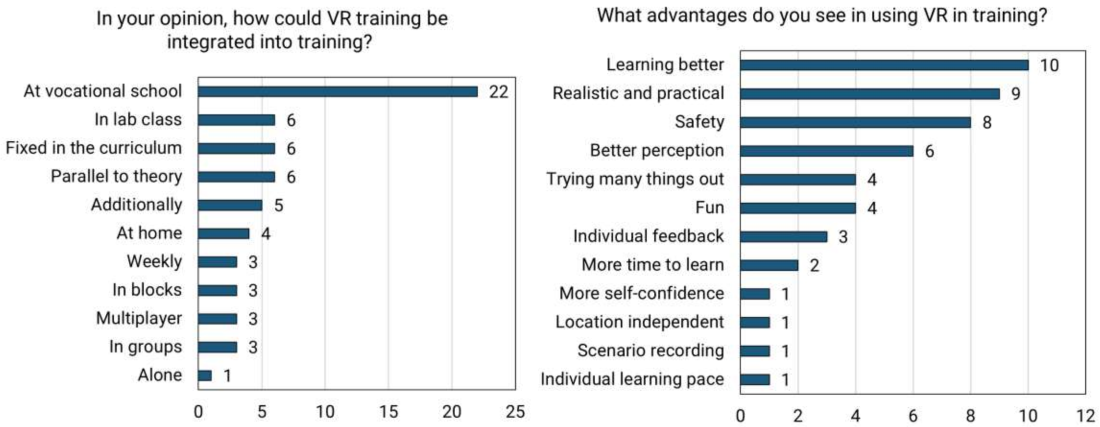

Figure 5.14: Seventh question: " In your opinion, how could VR training be integrated into training?" (left) and eight question: "What advantages do you see in using VR in training compared to conventional methods?", DigiLernSicher scenario (N=30).

Question 8: What advantages do you see in using VR in training compared to conventional methods (frontal teaching, exercise in the training facility)?

The interviews also raised the question of what advantages the apprentices would expect if a VR-based training solution were also available as part of the apprenticeship training. The most common response mentioned in this context was that VR training could contribute to better learning success (10 participants). This was justified by the fact that realistic and practical exercises lead to certain work steps and processes being better remembered (9 participants) and that VR-based training would help to better understand certain work steps and their context, and be able to perform them (6 participants): *"One is really focused and actively dealing with the topic"*[17] (p. 8). One participant also cited the direct body experience as a reason why realistic practice can contribute to more sustainable learning success *"the body remembers the movements that you make while practising, this is not monotonous; you can repeat each step at your own pace, get personal feedback and reflect on it"*[18] (p. 5). That VR training gives you the opportunity to train in a safe environment in which *"in principle you can't break anything"*[19] (p. 24) and *"no injuries can occur"*[20] (p. 2) were mentioned by 8 participants as a clear advantage. However, one participant added in this context that this could also be a disadvantage, because one might underestimate dangerous situations *"in such a playful scenario; one does not take it so seriously"*[21] (p. 5).

[17]"man ist wirklich drinnen und befasst sich aktiv mit dem Thema"

[18]"Der Körper merkt sich die Bewegungen, die man beim Üben macht, dies ist nicht monoton; man kann jeden Schritt im eigenen Tempo wiederholen, bekommt persönliches Feedback und reflektiert darüber"

[19]"man kann im Prinzip nichts kaputt machen"

[20]"es kann zu keinen Verletzungen kommen"

[21]"in so einem spielerischen Szenario kann man es unterschätzen; man nimmt es dann nicht so ernst"

Question 9: What challenges or difficulties do you see in using VR in education?

In addition to the advantages, possible challenges and difficulties of using VR-based training were also questioned. On the one hand, a critical factor mentioned by 4 participants was that the trainers and *"the directors had to play along"*[22] (p. 26). The reasons given for these concerns were, on the one hand, a possibly insufficient acceptance of technology, but also possible doubts regarding the teaching staff, that the use of a VR-based training solution could lead to poorer learning results. The fact that you *"may have to check what is being done in VR, because we then also tried out the roller coaster, that was bad"*[23] (p. 13) was also identified as a possible challenge by the apprentices (4 participants). Also concerns, *"that the glasses are always charged when you need them"*[24] (p. 27) were expressed by several participants in this context (4 participants). Further suggestions expressed by several participants concern the possibly too high acquisition costs of the system, or that practising the learning content is *"too much fun and then no longer takes other things such as theory or practising in the workshop so seriously"*[25] (p 10). As a further challenge, four participants mentioned that *"in (normal) lessons you (could) easily ask questions; in the VR, however, the teacher does not see what you are doing, so it may be more difficult for him to help"*[26] (p. 17) or, in general, that support must be given for coping with the training scenario (4 participants). As an idea to meet this challenge, several participants suggested streaming the VR content onto a screen - *"then the teacher can answer questions"*[27] (p. 17). Introductory videos and tutorials were also mentioned as good support options, especially because they could relieve the trainers.

Question 10: How could the trainers/teachers be involved with regard to VR training and what roles could they have?

The role of the trainers in coping with the VR-based training was also actively addressed in the interviews. The most common point mentioned by the apprentices in this context was that the scenarios should be mastered in the presence of the trainers or teachers (13 participants). The main reasons are that a contact person is needed for content-related questions or technical problems (5 participants), but also that this is necessary for a proper exercise process: *"It certainly doesn't work without a teacher; they always have to be there when practising, otherwise it would be far too unsettled (and noisy in the*

[22] "die Direktoren müssen mitspielen"

[23] "vielleicht kontrollieren muss, was in der VR gemacht wird weil wir haben dann auch die Achterbahn ausprobiert, das war arg"

[24] "dass die Brillen immer geladen sind, wenn man sie braucht"

[25] "mit zuviel Spaß nimmt und dann andere Dinge wie Theorie oder das Üben in der Werkstatt nicht mehr so ernst nimmt"

[26] "im (normalen) Unterricht kann man leicht Fragen stellen; in der VR sieht der Lehrer aber nicht, was man tut, da kann er dann vielleicht schwerer helfen"

[27] "dann kann der Lehrer Fragen beantworten"

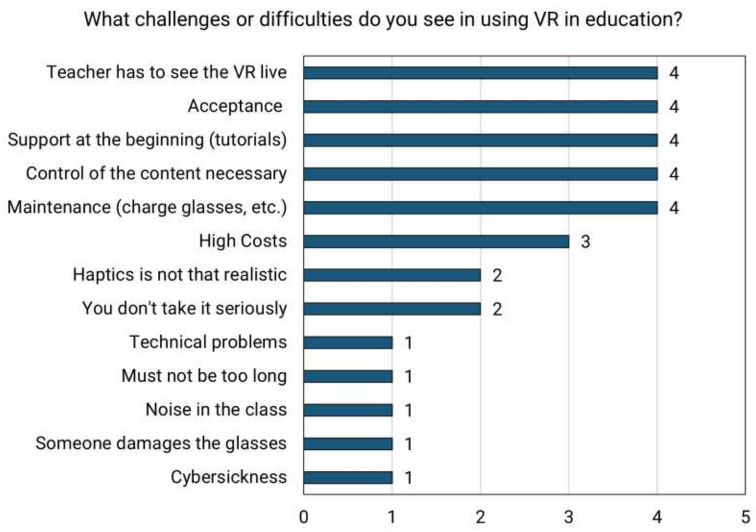

Figure 5.15: Ninth interview question: "What challenges or difficulties do you see in using VR in education?" (N=30)

class).”[28] (p. 20). The apprentices also suggested a possibility in which the trainer would use the VR-based training environment to clearly explain new learning content as part of the theory lesson (11 participants). The fact that the trainer should receive feedback whether the apprentices were successful in performing the tasks in the VR was also addressed as an important point by several participants (7 participants), this should be the prerequisite for the trainers giving the apprentices personal feedback, or to unlock simpler or more difficult scenarios (10 participants). An insight into the results of coping with the scenario would also help the trainers to *“connect this to the lesson and (can) perhaps repeat things where there are problems”*[29] (p. 17).

5.1.4 Observations

When contacting possible partners to test the prototype, an often encountered problem was, that the curricula was already full and there was no space for any additional activities. Many trainers asked were not willing to oversee the training in the break, since this time would be not paid and there are no additional funds to cover these expenses. Eventually, the proposal to use the VR training in the breaks was accepted by trainers who were very interested in the technology. However, it was still difficult to reach out to teachers who might be interested.

[28]“Ohne Lehrer funktioniert das sicher nicht; die müssen beim Üben immer dabei sein, sonst wäre es viel zu unruhig.”

[29]“das mit dem Unterricht verbinden und vielleicht Dinge wiederholen (können), wo es Probleme gibt”

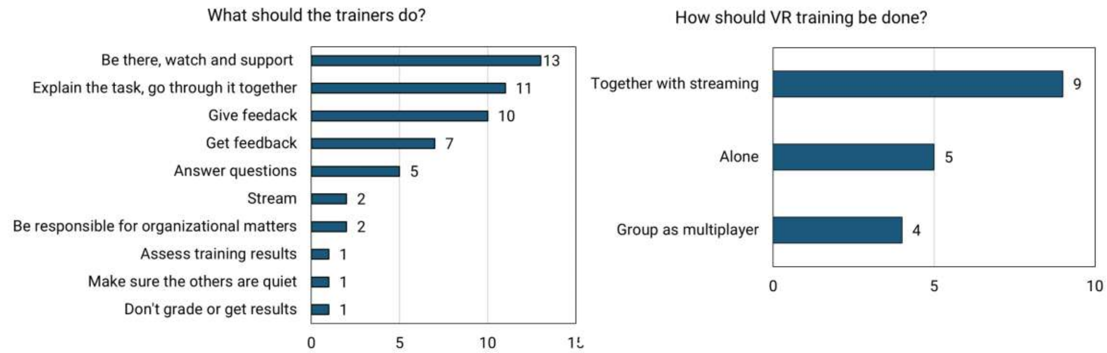

Figure 5.16: Tenth question: "How could trainers/instructors be involved with regard to VR training and what roles could they have?", DigiLernSicher scenario (N=30).

5.2 XRTrain

After an overview of the demographic data of all the study participants, this section presents the qualitative and quantitative results of the two experiments, the spatial orientation scenario and the medical trolley scenario, conducted in the XRTrain project.

5.2.1 Spatial Orientation Scenario

In the first section, the demographic characteristics of all participants of the spatial orientation scenario are described. Later, only the results of the group using VR are described, since the questionnaires focus on the aspects of VR and allows for comparability with the other experiments, and therefore focus on answering the research questions. The differences between the two training conditions are described briefly.

Demographic Data

The experiment was conducted with 41 participants, of which 20 trained with VR. Characteristics of all participants are described in table 5.4. The affinity for technology interaction (ATI-S) according to the scale by Wessel et al. [WAF19] was low to average (see figure 5.17). The participants also reported very low experience with computer games and VR.

Presence

The standardized scale IPQ (igroup Presence Questionnaire) [Sch03] was used to measure presence. The virtual training environment for spatial orientation shows high values (see figure 5.19) with M=1.36, SD=2.06. The general presence (PRES), spatial environment (SP), involvement (INV) and realisticness (REAL) are all rated similarly high.

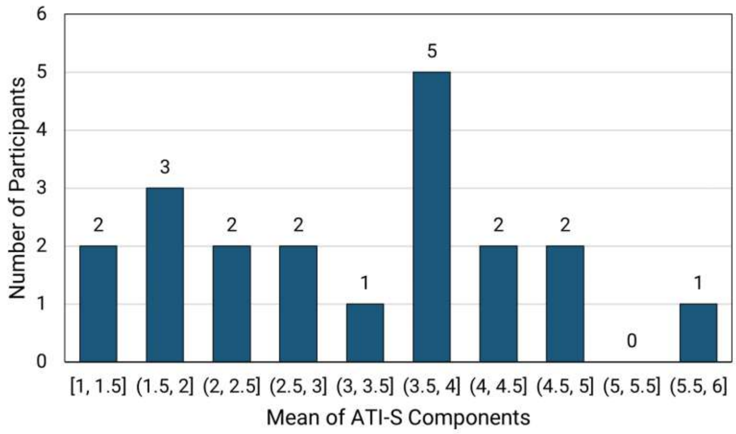

Figure 5.17: Histogram of mean ATI-S values in the spatial orientation scenario (N=20).

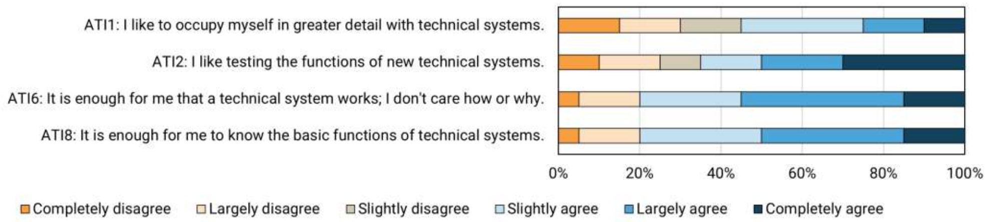

Figure 5.18: The distribution of the answers to the ATI-S scale in the spatial orientation scenario (N=20).

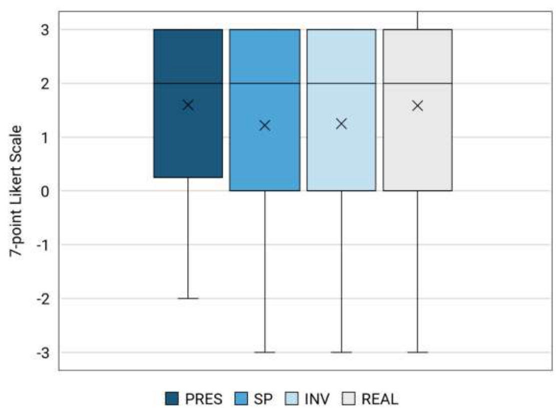

Figure 5.19: Histogram of IPQ components in the spatial orientation scneario, Likert scale from -3 to 3 (N=20).

	VR	noVR	Total
Number	n = 20	n = 21	n = 41
Age			
M	33.10	34.05	33.58
SD	8.99	9.65	9.22
Min	21	21	21
Max	51	52	52
Sex (in %)			
Female	85.00	95.24	87.81
Male	15.00	4.76	12.19
Highest Degree of Education			
Compulsory school	1	0	1
Apprenticeship	9	7	16
High-school	7	7	14
University	3	6	9
Affinity for Technology (6-Likert Scale, 1-6)			
M	3.28	3.50	3.39
SD	1.25	1.34	1.28
Gaming Experience (5-Likert Scale, 1-5)			
M	1.90	1.70	1.80
SD	1.25	0.98	1.11
VR Experience (5-Likert Scale, 1-5)			
M	1.5	1.45	1.48
SD	0.76	1.00	0.88

Table 5.4: Demographic data of the participants in the spatial orientation scenario.

User Experience

The results of the short user experience questionnaire (UEQ-S) (see figure 5.20) show positive results in all dimension, however, the training was perceived as not very easy. On the other hand, the training was rated as highly exciting, inventive and leading edge. Also, the majority of the participants perceived the training as clear and efficient.

The results of the Virtual Reality Neuroscience Questionnaires (VRNQ) indicate very positive user experience (see figure 5.21). The average values for all participants are described in tables 5.5 and 5.6. The degree of experienced immersion was rated as high by the majority of participants. The enjoyment of the VR experience and graphic quality were rated even better, with almost all feedback ranging from high to extremely high. The quality of the VR technology overall, i.e. including the hardware, was also perceived as very high.

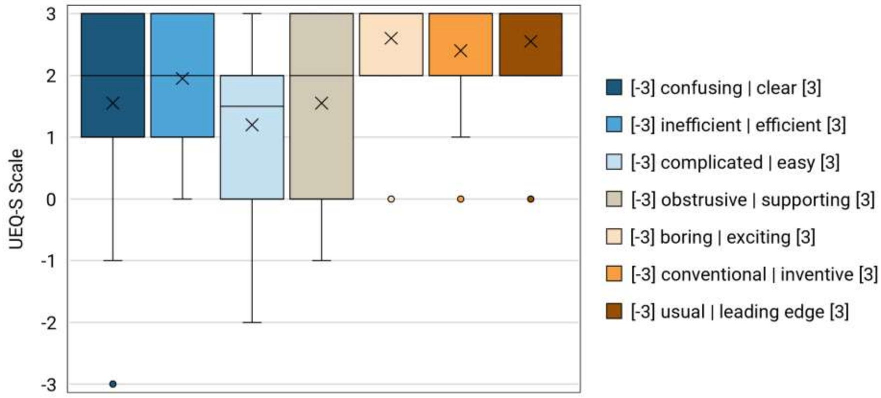

Figure 5.20: Results of the User Experience Questionnaire (short) in the spatial orientation scenario, scale from -3 to 3 (N=20).

	What is the level of immersion you experienced?	What was your level of enjoyment of the VR experience?	How was the quality of the graphics?	How was the quality of the VR technology overall (i.e. hardware and peripherals)?
AVG	5.35	5.80	6.00	6.20
SD	1.04	1.54	0.97	0.76

Table 5.5: Virtual Reality Neuroscience Questionnaire - User Experience in the spatial orientation scenario, Scale 1 to 7, (N = 20).

	Did you experience nausea?	Did you experience disorientation?	Did you experience dizziness?	Did you experience fatigue?	Did you experience instability?
AVG	6.90	4.60	6.75	6.55	6.00
SD	0.31	2.06	0.55	1.05	1.49

Table 5.6: Virtual Reality Neuroscience Questionnaire - VR Induced Symptoms and Effects in the spatial orientation scenario, Scale 1 to 7 (N = 20).

With regard to the motion sickness felt during the VR training, the results of the VRNQ scale show that the majority of the participants did not experience any intense problems with nausea, dizziness, fatigue or stability when using the VR environment. Overall, about a 20% of the participants reported experiencing moderate or intense and another 20% very intense or extreme feelings of disorientation. These are twice as many participants reporting disorientation as in the medical trolley scenario. This indicates that these problems might be caused by the scenario itself and the way of movement in the virtual space without moving one's body.

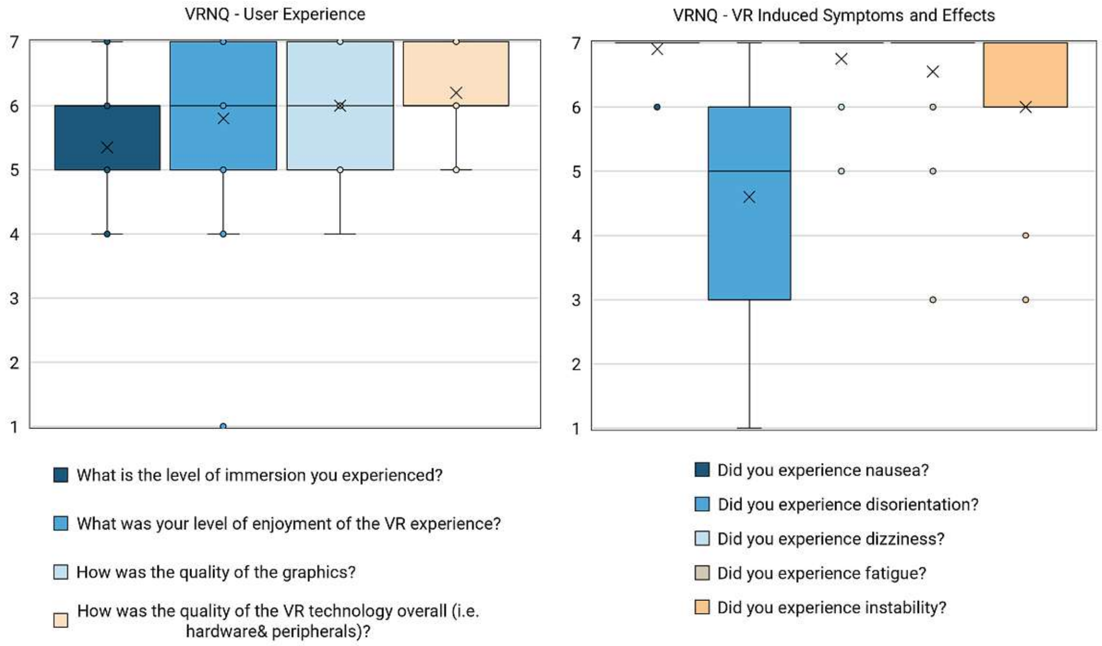

Figure 5.21: Virtual reality neuroscience questionnaire answers in the spatial orientation scenario, hedonic quality (left) and pragmatic quality (right), Likert scale from 1 to 7 (N=20).

Technology Acceptance

The training was accepted positively by the majority of participants (see figure 5.22). The virtual environment was found to be easy and comfortable to use by a majority of the participants. Most of the participants also found it easy to learn how to use the VR environment. Also, most of the participants were generally satisfied with the spatial orientation training scenario. The fact that the training was rated as less accessible by some participants might be caused by problems with orientation during the training. This scenario was rated as less accessible than the medical trolley scenario. In addition, the training felt frustrating to 20% of the participants and 40% encountered difficulties during the training. However, 90% largely or completely agreed that the training was fun.

Eye Tracking

For the analysis of the the eye-tracking data, Tobii Pro Lab software was used. Since each participant moved at a different pace, the relative attention count to points of interests was measured to create the heat maps. This analysis tool is recommended for dynamic situations of constant movement [Con18]. The footage from first entering the base image frame until fully moving out of it, was mapped. The base images were chosen based on the frequency of errors, hesitations and hints occurring at the respective

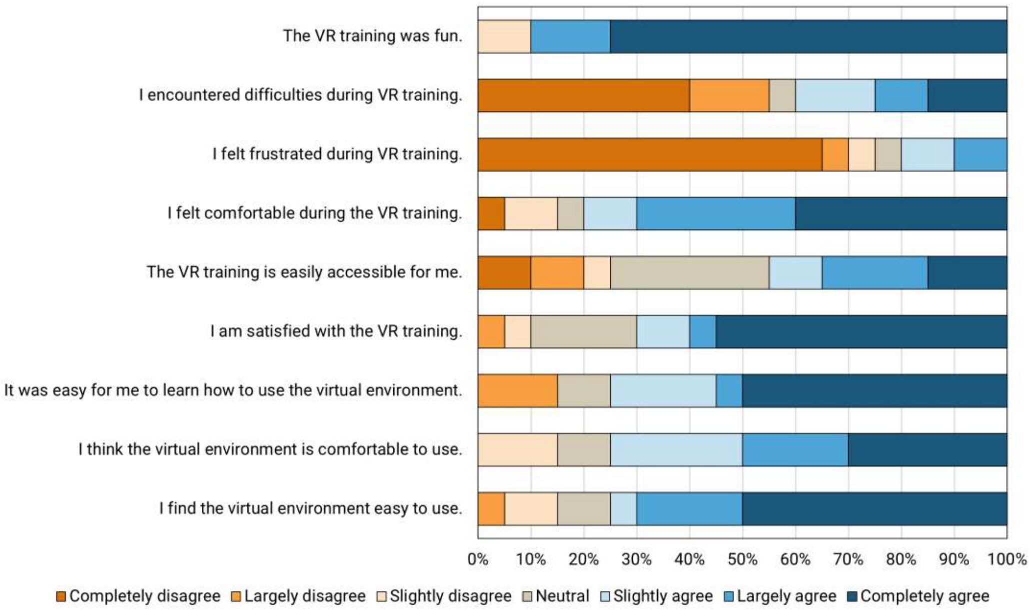

Figure 5.22: Distribution of answers to questions about the experience with VR training and technology acceptance in the spatial orientation scenario (N=20).

locations. The two locations visualized in figure 5.23 were particularly problematic for many participants.

The results indicate, that the participants of the noVR group were paying more attention to the room numbers, whereas the VR group was looking for visual cues, such as glass doors in the hallway, the number of doors between rooms or the position of the room relatively to corners. In the top left image (VR), the room number was not as an important point of interest, as in the top right image (noVR). The importance of other visual cues for the VR group is well visible in the bottom left image, where more participants paid attention to the glass door at the end of the hallway and to the glass window on the right.

Figure 5.23: Eye tracking heat maps from the spatial orientation scenario visualizing relative attention count. VR group left, noVR group on the right.

5.2.2 Medical Trolley Scenario

This section present the results of the medical trolley scenario. First, the demographic characteristics of all participants of this scenario are described. Further, the questionnaire results regarding the VR training are presented, therefore, only the group participating in the VR training is included.

Demographic Data

The affinity for technology interaction (ATI-S) scale by Wessel et al. [WAF19] shows low to middle values (see figure 5.24). The detailed answers are visualized in figure 5.25. The participants also reported very low experience with computer games and VR.

Presence

The IPQ scale (igroup Presence Questionnaire) [Sch03] was used to measure presence. The virtual training environment for spatial orientation shows high values (see 5.26) with M=1.54, SD=1.89. The general presence (PRES), spatial environment (SP), involvement (INV) and realisticness (REAL) are all rated high.

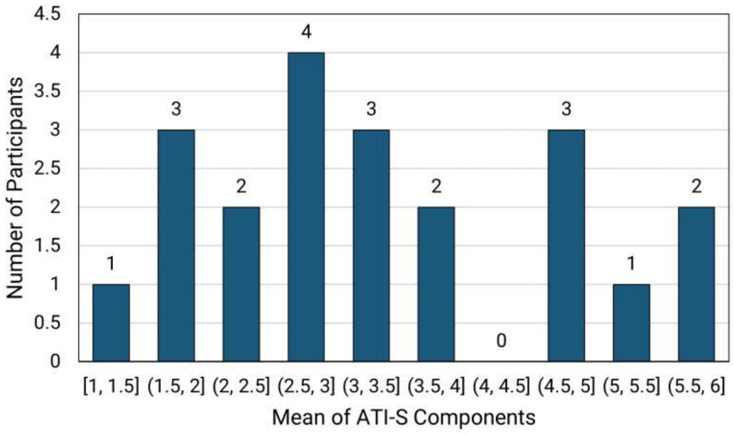

Figure 5.24: Histogram of means of ATI-S scale in the medical trolley scenario (N=21).

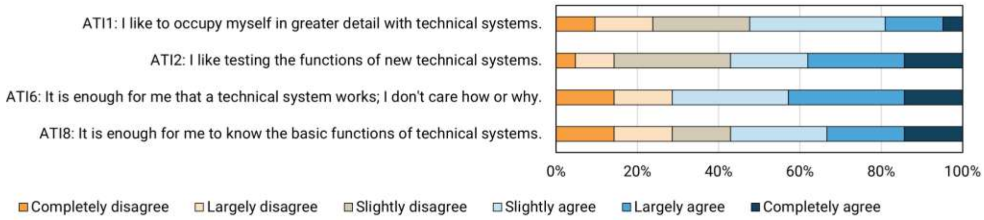

Figure 5.25: Distribution of the answer to the ATI-S questions in the medical trolley scenario (N=21).

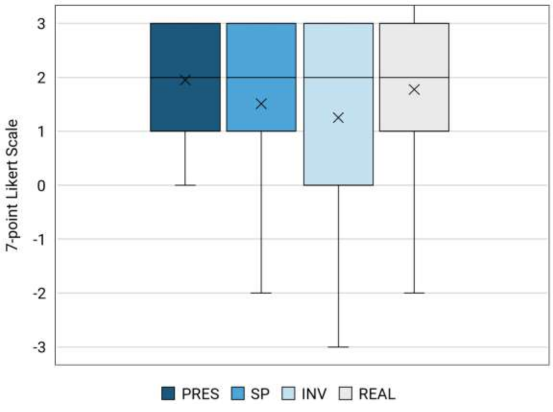

Figure 5.26: The means of the IPQ scale components in the medical trolley scenario (N=21)

	VR	noVR	Total
Number	n = 21	n = 20	n = 41
Age			
M	32.95	32.58	32.53
SD	14.71	11.26	9.37
Min	21	21	21
Max	52	51	52
Sex (in %)			
Female	95.24	90	92.68
Male	4.76	10	7.3
Highest Degree of Education			
Compulsory school	0	1	1
Apprenticeship	6	10	16
High-school	8	7	15
University	7	2	9
Affinity for Technology (6-Likert Scale, 1-6)			
M	3.28	3.50	3.39
SD	1.25	1.34	1.28
Gaming Experience (5-Likert Scale, 1-5)			
M	1.67	1.85	1.76
SD	0.97	1.31	1.40
VR Experience (5-Likert Scale, 1-5)			
M	1.29	1.7	1.49
SD	0.72	0.92	0.84

Table 5.7: Demographic data of the participants in the medical trolley scenario.

User Experience

The results of the short user experience questionnaire (UEQ-S) (see figure 5.27) show positive results in all dimension, however, the training was perceived as not very easy. On the other hand, the training was rated highly exciting, inventive and leading edge. Also, the majority of the participants perceived the training as clear and efficient.

The results of the Virtual Reality Neuroscience Questionnaires (VRNQ) show very positive user experience (see figure 5.28). The average values for all participants are presented in tables 5.8 and 5.9. The degree of experienced immersion was rated as high to extremely high by the majority of the participants. Satisfaction with the VR experience was rated even better, with almost all feedback ranging from high to extremely high. The quality of the VR technology overall, i.e. including the hardware, was also perceived as high to very high by most participants. The graphic quality of the scenario was still

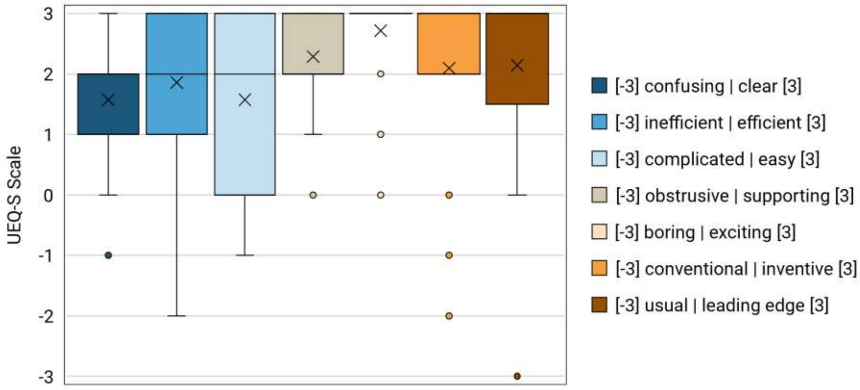

Figure 5.27: Results of the User Experience Questionnaire (short) in the medical trolley scenario (N=21)

	What is the level of immersion you experienced?	What was your level of enjoyment of the VR experience?	How was the quality of the graphics?	How was the quality of the VR technology overall (i.e. hardware and peripherals)?
AVG	5.59	6.00	5.23	5.73
SD	1.14	1.02	1.19	1.21

Table 5.8: Virtual Reality Neuroscience Questionnaire - user experience results in the medical trolley scenario, Scale 1 to 7, (N = 20).

	Did you experience nausea?	Did you experience disorientation?	Did you experience dizziness?	Did you experience fatigue?	Did you experience instability?
AVG	6.54	5.73	6.18	6.63	6.00
SD	1.10	1.58	1.30	1.05	1.54

Table 5.9: Virtual Reality Neuroscience Questionnaire - VR Induced Symptoms and Effects results in the medical trolley scenario, Scale 1 to 7 (N = 20).

rated high, however less than the other components of the hedonic qualities.

With regard to the motion sickness felt during the VR training, the results of the VRNQ scale show that the majority of the participants did not experience any intense problems with nausea, dizziness, fatigue or stability when standing in the VR environment. Overall, about a quarter of the participants reported experiencing moderate or intense feelings of disorientation, however, much less than in the spatial orientation scenario. This indicates that individual participants had problems operating the system with regard to this aspect.

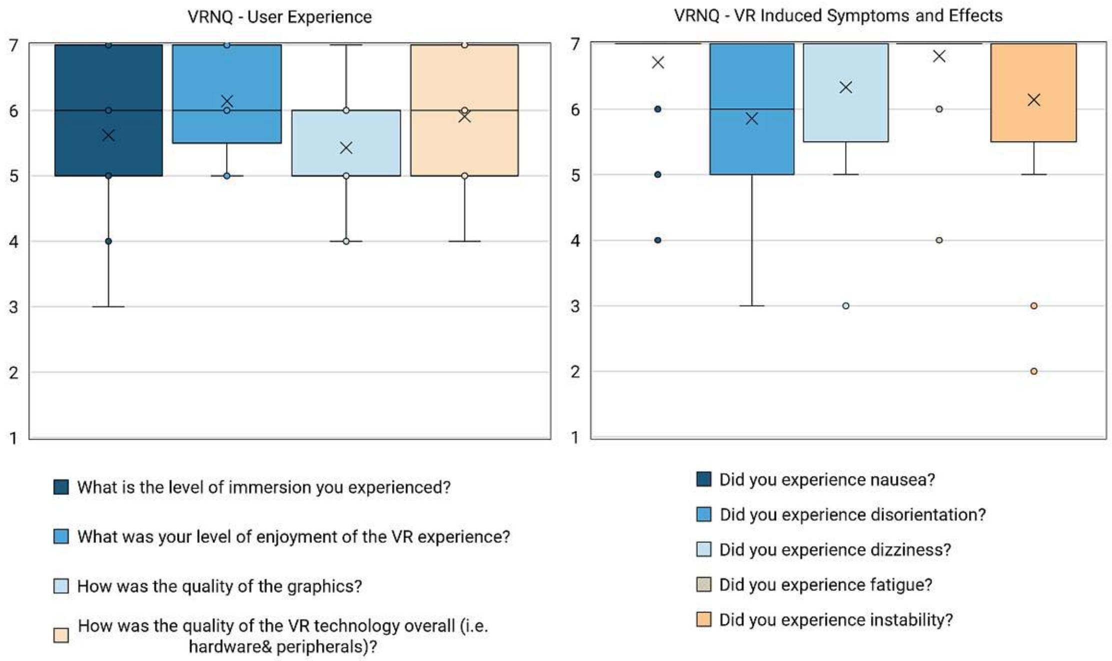

Figure 5.28: Virtual Reality Neuroscience Questionnaire (VRNQ) answers in the medical trolley scenario, hedonic quality (left) and pragmatic quality (right), Likert scale from 1 to 7 (N=21).

Technology Acceptance

With regard to the acceptance of the evaluated training solution, the results of the field study show consistently positive values (see figure 5.29). The virtual environment was found to be easy and comfortable to use by the majority of the participants. Most of the participants also found it easy to learn how to use the VR environment. Most of the participants were generally satisfied with the medical trolley training scenario. The fact that the training was rated as less accessible by some participants might be caused by problems with blurry vision mentioned by some participants, who could not wear glasses during the training. Furthermore, the results also show that all participants felt very comfortable during the training. About 15% of the participants encountered some kind of difficulties, however, no one reported feeling frustrated during the VR training.

5.2.3 Comparison of the Training Methods

The observation protocols give an insight in the performance during the tasks. In terms of task performance in the spatial orientation scenario: time per task, number of errors, number of moments hesitating, number of hints and mental load. The group training with VR performed worse than the group training with printed materials in all the described metrics. The On the other hand, the results of the medical trolley scenario are very different. The VR group performed better in terms of time per task, number of errors

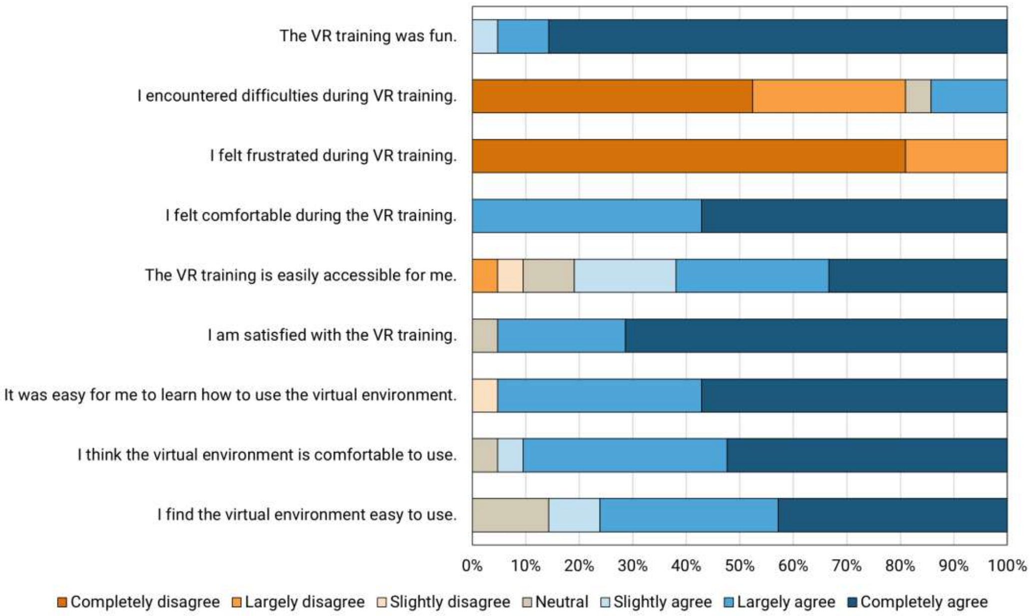

Figure 5.29: Distribution of answers to questions about the experience with VR training and technology acceptance in the medical trolley scenario (N=21).

and number of requested hints.

These results align with the answers given in the TAM questionnaire, where the spatial orientation scenario was perceived as less comfortable, less easy to use, more complicated to operate and more frustrating than the medical trolley scenario.

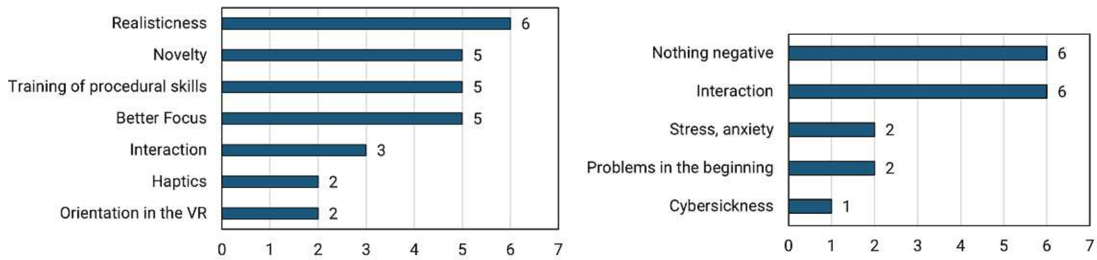

Figure 5.30: First: "What did you find positive about the training, what worked well?" (left) and second question: "What did you find negative about the training, what didn't work so well?" (right), XRTrain (N=16).

5.2.4 Interviews

Sixteen participants training in VR were interviewed, of them 7 completed the VR training for the spatial orientation scenario and 9 for the medical trolley. All interviews were conducted immediately after finishing the tasks.

Question 1: What did you find positive about the training, what worked well?

The majority of the participants rated the training positively (see figure 5.30). The main aspects were realisticness (6 participants), novelty (5 participants), training of procedural skills (5 participants) and better focus (5 participants): *"Remembering the surroundings is much better when I experience it directly instead of through pictures and videos."*[30] (p. 3). One participant found the experience overwhelming: *"I noticed right away that it wasn't for me - overwhelmed, too many stimuli"*[31], however: *"I did not get (cyber)sick. That was very surprising and positive."*[32] (p. 10). Three participants described the interaction as easy, and two participants mentioned that they liked the haptic aspects of manipulating objects instead of only learning by reading. Two other participants enjoyed that they could walk around, and better imagine the building structure and orient themselves in the building.

Question 2: What did you find negative about the training, what didn't work so well?

Six participants did not find anything negative about the training (see figure 5.30). The most frequently mentioned negative aspect was the interaction in the scenario: *"Once I got stuck with the hand in the drawers and also accidentally teleported myself"*[33](p. 2).

[30] "Merken der Umgebung ist viel besser wenn ich es real erlebe statt durch Bilder und Videos."
[31] "Hab gleich gemerkt, dass das nix für mich ist - überfordert, zu viele Reize"
[32] "Nicht übel geworden! Das war sehr überraschend und positiv."
[33] "Nur einmal mit der Hand bei den Schubladen hängenn geblieben und einmal habe ich mich aus versehen rausgebeamt."

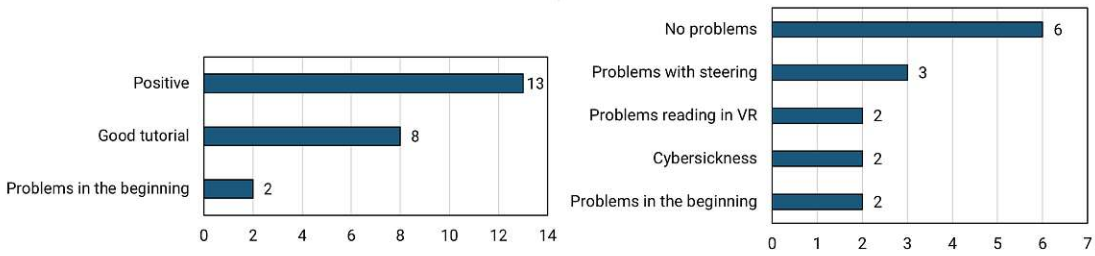

Figure 5.31: Third: "Did you find the training easily accessible - why? Why not?" (left) and fourth question: "Did you have difficulties during the VR training? If yes, which?" (right), XRTrain (N=16).

The problem with stuck hand appears three times, so it might have been a technical problem of the controller. Two participants experienced difficulties with fine motor hand movement when positioning the instruments on top of the trolley (p. 12, 16). One participant mentioned difficulties because of tarnished glasses (p. 9), which was caused by wearing the mask, which was mandatory due to the current COVID-19 situation. The scenario guardian caused troubles and anxiety to two participants: *"the net - I had to go in all the time."*[34] (p. 15). Also, one participant described feeling symptoms of cybersickness during and after the training.

Question 3: Did you find the training easily accessible - why? Why not?

Out of 16 participants, 13 rated the training as easily accessible (see figure 5.31): *"I like to try out things, for me a very easy and quick to understand technology."*[35] (p. 14). The most frequent reason for the positive statements was the good tutorial in the beginning that helped them to understand the interactions and get familiar with the VR. Two participants still experienced problems in the beginning of the scenario, however, they did not perceive them solely negatively: *"I needed a bit, but the difficulties were perhaps also helpful."*[36] (p. 7). Most of the problems, which occurred in the beginning, could be overcome with time.

Question 4: Did you have difficulties during the VR training? If yes, which?

When asking about experienced difficulties (see figure 5.31), six participants mentioned they did not have any problems. Three participants described problems with steering (mostly haptics), which are already described in Question 2. Another problem was reading in VR, especially for people who usually wear glasses and were not able to wear them under the VR HMD or their glasses were tarnished. In addition, these problems with blurry vision occurred together with symptoms of cybersickness.

[34] "Das Netz - musste immer rein gehen."
[35] "Ich probiere gerne Sachen aus, für mich eine sehr leichte und schnell verständliche Technologie."
[36] "Habe etwas gebraucht, die Schwierigkeiten waren aber vielleicht auch hilfreich."

Figure 5.32: Fifth: "Were you satisfied with the VR training? Why? Why not?", XRTrain (N=16).

Question 5: Were you satisfied with the VR training? Why? Why not?

A majority, 88% of the interviewed participants, were satisfied with the VR training (see figure 5.32). The reasons for satisfaction with the VR training were positive learning experience (6 participants), fun and realisticness (3 participants each) and novelty (2 participants). The connection between theoretical and practical knowledge was described as very important: *"You can gain confidence in situations when theoretically learned, and then done practically in VR, then in real."*[37] (p. 4). Another important point was the similarity of movement when preparing for the task and during the task itself: *"I was well prepared (for the exercise), I've seen it before the exercise, it was then the same moves again."*[38] (p. 6).

Question 6: Do you have any suggestions for improvement regarding the VR training (related to spatial orientation or intubation, depending on which training was completed previously)?

The training could be improved by adding more variety and realisticness (2 participants) (see figure 5.33), for example, by changing the starting position of the objects slightly (because in reality, things are not perfect) (p. 11). Also, adding distractions and more complexity, would make the experience more realistic. Two participants who did the spatial orientation scenario pointed out, that more detailed visual cues would have been helpful (p. 9, 15).

Question 7: Would you like to complete VR-based training in education and training?

All participants agreed that they would like to complete VR-based training in their education, however, one participant added that they would only like to do VR trainings

[37] "Man kann Sicherheit gewinnen bei Situationen, theoretisch gelernt, dann praktisch in der VR gemacht, dann echt."

[38] "War gut vorbereitet (auf die Übung) hab es schon vorher gesehen gehabt zur Übung, es wared dann gleiche Handriffe nochmal."

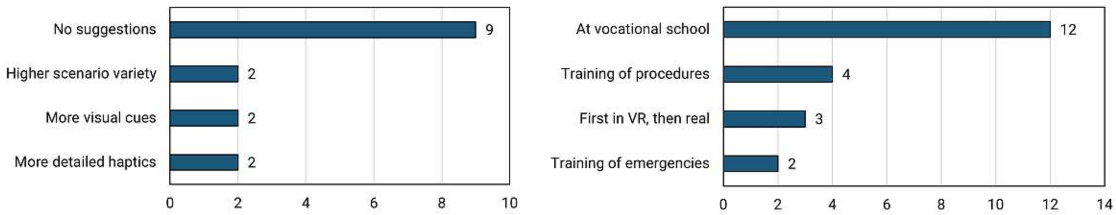

Figure 5.33: Sixth: "Do you have any suggestions for improvement regarding the VR training?" (left) and eight question: "In your opinion, how could VR training be integrated into training?" (right), XRTrain (N=16).

in other fields: *"For other issues - disasters preparation in jobs other than mine..."*[39], adding that: *"to watch someone die"* would lead to even more *"people leaving the field."*[40] (p. 10). All other responses were positive, two participants also mentioned the advantages for learning practical skills during lockdowns (p. 1, 2).

Question 8: In your opinion, how could VR training be integrated into training?

Regarding the integration of the VR training (see figure 5.33), 12 out of 16 participants suggested that the VR training should be integrated as a part of the curricula at the vocational school. A possible integration would include either blocked courses or regular sessions with VR training in the curriculum. Especially the training of procedures was mentioned as helpful (4 participants). Also, the advantage of practising a situation in VR first and then performing it in the real-world, was emphasized. A suitable scenario would be to: *"Reenact emergency situations and then again in real life, i.e. first experience them virtually instead of just explaining them."*[41] (p. 8).

Question 9: What advantages do you see in using VR in education?

The most frequently described advantages (see figure 5.34) are remembering better, the realisticness of the VR training and no risk and fear (4 participants each). *"Practical exercise helps me more than the theory."*[42] (p. 6), another participant added: *"The repetition makes it totally memorable. It's really not the real world, but very close. You are not afraid of making mistakes, trying things out and training."* [43] (p. 12). Another important mentioned points were location independence, less effort and its suitability for training procedural skills (3 participants each). *"For example, in Corona Distance*

[39]"Für andere Themen - Katastrophenvorbereitung in anderen Jobs als meinem..."
[40]"Zu schauen wie einer Stirbt, dann gibt es noch mehr Aussteiger."
[41]"Notfallsituationen nachspielen und dann auch noch mal in real, also erstmal virtuell erleben statt nur erklären."
[42]"Praktische Übung hilft mir mehr als die Theorie."
[43]"Die Wiederholung macht es total gut merkbar. Es ist echt nicht die reale Welt, aber sehr nah dran. Man hat keine Scheu vor Fehlern, Ausprobieren und Trainieren."

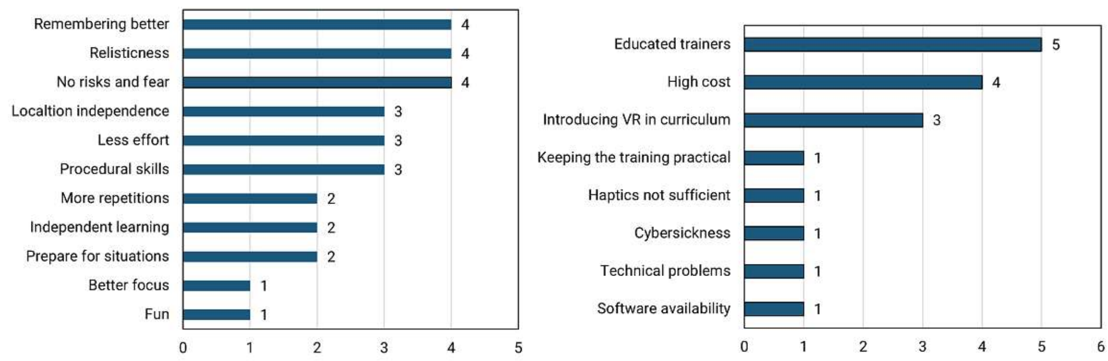

Figure 5.34: Ninth: "What advantages do you see in using VR in education?" (left) and tenth question: "What challenges or difficulties do you see in using VR in training?" (right), XRTrain (N=16).

Learning. I don't need a lot of equipment (to practice), even small schools have everything with the (VR) HMD."[44] (p. 11).

Question 10: What challenges or difficulties do you see in using VR in training?

The main concern regarding the use of VR in education is the level of acceptance among trainers and their knowledge of the technology (see figure 5.34), which is a premise for successful integration and application of VR in the curriculum. This would also require that: *"The teachers must know the handling - it's hard to imagine that our teachers are able to do that, own professionals are necessary."*[45] (p. 11) and the teachers would need *"training programs for troubleshooting and training to be able to explain the application."*[46] (p. 6), together with handling technical problems. Another issue might be the cost of the equipment (4 participants) and the process of introducing the VR into curricula (3 participants). Further concerns include keeping the training realistic enough and not learning wrong behaviour due to possible inaccuracy of the system. Also, cybersickness, insufficient accuracy of the haptics and the availability of software might be problematic: *"Claustrophobia, anxiety, disorientation and dizziness are personal difficulties that need to be taken seriously."*[47] (p. 8).

[44] "Zum Beispiel in Corona-Distanz-Learning. Ich brauch nicht viel Equipment, auch kleine Schulen haben mit der Brille dann alles."

[45] "Der Unterrichtende muss das Handling haben. Bei unseren Lehrern ist das kaum vorstellbar, eigene Profis sind nötig."

[46] "Schulungsprogramme auch für Problembehebung und Schulung zum Erklären der Anwendung."

[47] "Klaustrophobie, Angst, Orientierungsschwierigkeiten und Schwindel sind persönliche Schwierigkeiten, die ernst genommen werden müssen."

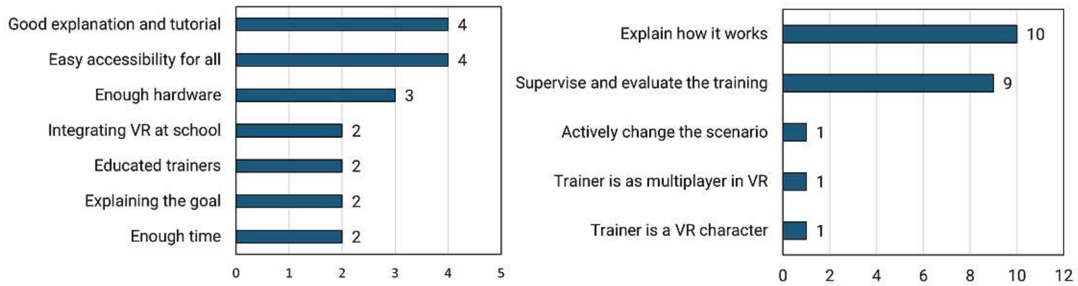

Figure 5.35: Eleventh: "What should one pay attention to in order to make VR training accessible to all people in training?" (left) and twelfth question: "How could trainers/instructors be involved in VR training, or what roles could they have?" (right), XRTrain (N=16).

Question 11: What should one pay attention to in order to make VR training accessible to all people in training?

A good introduction how to use the system including explanation and tutorial and easy accessibility for all are important points mentioned by 4 participants each (see figure 5.35). One participant formulated this as to: *"give good explanations and formulate goals - why do we do it"*[48] (p. 11). Also, having resources, enough hardware and time is very important, since the time is already a problem in the current education: *"Usually there is too little time, hardly any practice time and hardly any learning time."*[49] (p. 2). Another participant suggested that the training should be: *"standardized and give everyone the chance to practice repeatedly and regularly, by integrating the (VR training) in each semester."*[50] (p. 4).

Question 12: How could trainers/instructors be involved in VR training, or what roles could they have?

The majority mentioned (see figure 5.35) that the trainers should explain how the system works (10 participants) and then supervise the training, do training evaluation (9 participants) and discuss the training afterwards with the users: *"Explain - what will happen, explain tasks, clarify questions about VR and be available."*[51] (p. 12). In particular, it was suggested, that the supervision in the VR could be done by a virtual character of the trainer, or by the trainer joining by a multiplayer (1 participant each).

[48] "Gute Erklärungen geben und Ziele Formulieren - wofür machen wir das."
[49] "Meist gibt es zu wenig Zeit, kaum Übungszeit und kaum Lernzeit."
[50] "Einheitlich machen und jedem die Chance geben das zu machen, in allen Semestern integrieren - Regelmäßigkeit und zusätzlicht freies Üben möglich machen."
[51] "Erklären - was wird passierern, Aufgaben erklären, Fragen zur VR klären und zur verfügung stehen."

5.3 Summary of the Results

The groups of DigiLernSicher and XRTrain strongly differed in the measured affinity for technology interaction, with the apprentices groups showing very high values and the nurses showing only low to average values. We can assume, that this group chose to do a technical apprenticeship because of their interest in technology. Moreover, the apprentices had more experience with computer games and VR.

The presence of all scenarios was rated as high. However, in the XRTrain experiments, the measured presence was higher than in the DigiLernSicher scenario. A possible explanation for this difference is the setting of the training. Whereas the participants in the XRTrain trained in a silent environment, separated from the rest of the group and with a full attention of a trainer (in this case a researcher overseeing the training), the DigiLernSicher group practised in a classroom or during a break, experiencing much more distractions and noises from the real environment.

In terms of user experience, all scenarios were perceived as clear and efficient and highly exciting. The main differences appear in the rating of how complicated or easy, and obtrusive or supporting the training was. The spatial orientation scenario was perceived as more complicated and obtrusive than the other scenarios. The medical trolley scenario was rated as most supporting and most exciting. Also, the apprentices rated the DigiLernSicher scenario less inventive, than the nurses the medical trolley and spatial orientation scenarios. Possibly due to more experience with computer games and VR, and thus having higher expectations. The Virtual Reality Neuroscience Questionnaire shows similar values across the hedonic qualities, but differences in the pragmatic qualities, especially in the component of experienced disorientation, which was the highest in the spatial orientation scenario. Also, in the interviews, difficulties with teleporting were described both in the DigiLernSicher scenario and the spatial orientation scenario and might be responsible for the measured differences. In these two scenarios, one needed to teleport themselves frequently in order to successfully finish the scenario. In general, the participants of DigiLernSicher reported more frequent symptoms of cybersickness, however, their training was not as carefully supervised as the training conducted in the XRTrain experiments, and the participants of DigiLernSicher reported spending longer time in the VR.

Realisticness, fun and novelty were emphasized as the main positive aspects by all groups. While fun was one of the most important factors for the apprentice groups, it was mentioned less frequently by the group of nurses. Better focus in the VR was pointed out by all groups. Participants across all groups described that they felt more focussed in the VR because they were not paying attention to the outer world and focused solely on the task in the VR environment. In addition, they reported faster understanding and better remembering of complex task, because of the movement similarity when practising them in VR and then performing them in the real-world setting.

Steering and navigation was perceived as difficult in the beginning, however later, this was not causing problems. A key to overcome the initial problems is a good tutorial, explanation of the training goals and support during the training session. Cybersickness was rare, however caused problems to individual participants. Possible improvement suggested by the participants includes more scenarios and higher scenario variety with multiple difficulty levels. Better haptic feedback would also be helpful, however, this is a well known limitation of the currently widely used VR HMD systems. The majority of the participants would welcome the integration of VR training at their vocational schools, especially for the training of complex procedures, which can be in this way practised virtually before performing them in the real world, facing real risks.

The trainers should introduce the students to the training, explain the goals and be present during the training, offering help and advice when needed. After the VR training, they should give feedback to students. Besides, they need to interact with the rest of the class, for example by streaming the training and so involving the other students. The main identified challenge of integrating such training system in the educations is the possible lack of interest or knowledge from the side of trainers and directors at vocational schools. Also, high costs, maintenance and related technical problems are a challenge.

Regarding technology acceptance factors, all scenarios were rated as fun by at least 85% of the participants of the scenario. The participants in the spatial orientation scenario encountered more difficulties and felt more frustrated than the participants of the medical trolley scenario, which shows the best results in all components of the questionnaire and also better results in terms of task performance. In all scenarios, over 70% of the participants responded that it was easy to learn how to use the virtual environment and that the VR was comfortable to use. The DigiLernSicher scenario was rated somewhat less positively in terms of ease of use, probably because of many participants came from different specializations and needed more time to understand the background of the training. Overall, the training was accepted very positively by the users and trainers participating in the experiments.

	DigiLernSicher	**Spatial Orientation**	**Medical Trolley**
ATI-S [WAF19]	4.25	3.50	3.28
Mean Presence (IPQ) [Sch03]	0.76	1.36	1.54
User Experience (UEQ-S) [SHT17]	Rated less inventive than the other two scenarios.	Rated as most leading edge, very exciting but less easy to use.	Rated as most exciting and supporting.
Hedonic Quality (VRNQ) [KCDM19]	High	Very high	Very high
Pragmatic Quality (VRNQ) [KCDM19]	Individual participants experienced nausea.	Individual participants experienced disorientation.	Very high
Technology Acceptance	Over 80% of the participants were satisfied with this training.	Rated lowest among all scenarios. Rated as fun by 90% of the participants, despite 40% reporting difficulties.	Over 95% of the participants were satisfied with the training and all rated the training as fun. Rated as best in all aspects among all scenarios.
Task Performance	Not assessed.	The VR group performed worse in terms of time per task, number of errors, number of moments hesitating and number of hints than the noVR group.	The VR group performed better in terms of time per task, number of errors and number of requested hints.

Table 5.10: Comparison of the results of the three experiments included in the case study.

CHAPTER 6

Discussion

6.1 Opportunities & Challenges

This section summarizes the key findings from Chapter 5, gives interpretations and describes implications for practical use with regard to the first research question:

RQ1: What are the opportunities and challenges of using single-user VR HMD in current professional training in terms of accessibility, learning outcomes, acceptance factors, and motivation to use the technology?

The results of the case study show consistently high values of presence. The virtual environment seems to be perceived as very close to reality, which is an important prerequisite for user acceptance [LBR+15]. However, some technical aspects of the training scenario have not yet sufficiently corresponded to reality - such as the design of the measuring device in the DigiLernSicher scenario, which in reality requires far more settings to be made before it can be used. In the context of presence, it is interesting that the users also actively questioned whether a high level of realism, which nevertheless has no consequences in case of errors, could lead to users becoming careless when operating the VR, but also when working in real environments. This point should be examined more closely in follow-up studies, and further thoughts should be given to new feedback mechanisms.

The user experience of all training scenarios was rated very positively. The implemented training solutions were perceived as interesting, exciting and novel. The scenarios were described as clear, efficient and original. The results of the interviews also show that mastering VR-based training is above all fun. Some participants reported, that through the VR training they were able to have a completely new, but interesting and very positive experience. The interaction in the VR training was praised as understandable.

In this context, the enrolment of the study staff was often positively highlighted by the participants. In the context of the user experience, it is also very positive to note that symptoms of cybersickness only pose an actual problem for very few participants. Still, the time spent in VR should not be too long, since it can increase the occurrence of cybersickness symptoms, especially nausea, as described by the participants of DigiLernSicher, whose time in the VR was not limited and was let upon their own decision. The symptoms of cybersickness must be taken seriously and help must be provided. The virtual environment was found to be easy and comfortable to use by the majority of the participants. It was easy for the participants to learn how to use the training scenarios. Only individual participants experienced the ways of interaction and navigation as challenging in the beginning, and could soon overcome the initial difficulties. Both the quantitatively collected data and the results of the interviews show that there is a high level of acceptance for the use of a VR-based learning environment in the context of professional training. These findings align with the Technology Acceptance Model (TAM) [Dav89], where high hedonic and pragmatic quality, very low cybersickness, together with ease of use and perceived usefulness of the system indicate a good user acceptance of the system.

Even tough teleporting is the recommended way of movement to reduce cybersickness [GGBZ21, TPB+17], it was causing interaction difficulties in scenarios requiring more movement by teleport and the results show more cases of disorientation. The spatial orientation scenario was perceived as more complicated than the others. A possible explanation is the amount of teleporting needed for the successful completion of the scenario. It was mentioned that the visual design of the scenario as quite uniform and emphasized that it would have been helpful to see more diverse visual cues. Another participant was critical of the line displayed that showed the way to the next room, which could lead to participants following the path, without actually focusing on the route and not actively memorizing it. The VR training seems to be less suitable for tasks involving spatial orientation, however this topic should be further investigated, since our results partially contradict the findings of the study by König et al. [KKC+21]. However, the lower performance of the VR group in this scenario might also have been caused by specific design characteristics of the scenario. On the other hand, the medical trolley scenario was rated as the most supporting and easy to use. In this case, all movements could be achieved intuitively by doing the same movements as in the real world: walking, rotating, grabbing and placing objects. In the interviews, it was emphasized, that doing movements in VR which are similar or the same as in the real-world make the whole procedure easier to remember and apply. Some participants noted, that they preferred natural walking to teleporting, however, this is difficult to implement when the distances in the virtual environment exceed the available training space. The overall satisfaction with the medical trolley scenario and electricians' scenario were higher than with the spatial orientation scenario. These results are supported by the findings of Renganayagalu et al. [RMN21] and Górski et al. [GGBZ21] identifying the training of procedural skills as the most frequent and suitable content for VR training.

The haptics of the used VR HMD and controller are not precise enough for technical activities requiring fine motor movements, such as soldering or working on electronic circuits. Therefore, the training should rather focus on other areas which are not affected by this problem or utilize more precise technology. These finding are not surprising, since the haptic feedback in commonly used VR systems is a well known limitation [PLS+21].

The results of the interviews and questionnaires could also confirm that VR-based training is particularly suitable for learning and practising complex scenarios in which different knowledge must be brought into context and applied correctly. Learning with VR enables to better see complex relationships and understand the bigger picture. Otherwise, the practical knowledge is often isolated. The users suggested that they would like to use VR training to practice standardized procedures, which are not being practised enough in the current teaching. Due to the possibility to repeatedly practise action sequences in the VR, participants felt more secure about their knowledge. A majority of the participants also confirmed that dealing with safety-relevant situations can be handled more routinely and safely in a VR environment, enabling a more confident reaction to serious situations in reality. Situations that are practised in the virtual environment first can then be mastered more easily in reality and help to overcome fear. In addition, users have to actively deal and interact with the environment in order to learn effectively. VR training is also a suitable way of introducing new topics to students from different areas.

An important point mentioned by participants of all the three experiments is that they felt more focused when using the VR. The participants, especially those practising in VR for the medical trolley scenario, described the experience of remembering the way of movements and position of the objects in relation to their body. This claim is also supported by the findings of Krokos et al. [KPV19].

Even though it is possible to offer individual learning scenarios without a guidance of a trainer, our results support the findings of Popovici et al.[PM08] and Schwarz et al. [SRKS20], suggesting that VR training should be always supervised. The interviews show a clear preference for guidance and support by the trainers. Advanced users might need less support and practice more independently. When evaluating the VR training, the trainers suggested that such training can be integrated in the classes by streaming the content of the scenario on a big screen and thus making the content available for all students simultaneously and so enabling them to interact with all students. In this way, the trainer can also show how to perform the tasks correctly. One way of reducing the load of the trainers is the development of interactive tutorials explaining the use of the hardware and software, which can be used by the users independently. Regarding the tutorial in the beginning, using video material explaining the scenario content and interaction seem to be the most feasible option. All students can view the tutorial at the same time and discuss its implications for the training. On the other hand, a tutorial integrated in the VR might be more intuitive, however requires longer time spent in VR per participant, which might cause a bottleneck and require more equipment and resources in general. The mechanisms via which the trainers receive feedback on how the students performed in the training scenarios (e.g. on problems that arise) also need to be designed, as well as ways to enable the trainers to participate synchronously while completing the tasks. Furthermore, the responsibilities for the ongoing maintenance of the hardware must be clearly defined. Additionally, the guardian, that is the net visualizing the border of the safe area, was found confusing by some participants, therefore, it is of high importance to explain and show the participants beforehand, how the guardian works, to prevent confusion and anxiety. It is also important to give enough time for adjusting the HMD so that the vision is clear.

Training with VR should not be mandatory, since not all participants felt comfortable. This is also stated by Schwarz et al. [SRKS20] who sees training with VR as supplementary to the usual training. However, the majority of the participants would perceive the training as enrichment of the usual learning methods, as also suggested by Plotzky et al. [PLS+21]. Moreover, it was pointed out that training in VR can only be a good addition and cannot replace real practice, which is also stated in the study by Bracq et al. [BMA+19].

Most of the challenges arise with regard to the further development of the training content and the embedding of VR-based training solutions in everyday teaching. Also, the equipment itself and the development of the scenarios are still quite costly. The most viable seems the introduction of VR-based training in classes at vocational schools. In this context, scenarios provided by a higher institution which can be widely used across many vocational schools can help reduce the cost. On the content level, the training solution must be expanded in the next step, to include further learning content, providing fitting content for different years of training, but also supporting various levels of difficulty.

The interviews show, that different levels of difficulty would be helpful, especially in the DigiLernSicher scenario, since the participants had varying level of knowledge. The importance of scenario flexibility and scalability is also suggested by Mossel et al. [MPGK15]. Different difficulty levels were not foreseen in this project, however, future VR for professional training should implement them. These could also be generated, based on the past errors of respective user or implement situations such as distractions, other non-playable characters or subtle changes such as changed position of objects, which might bring the training closer to the real-world situation. In order to achieve the highest possible degree of realism, it is absolutely necessary that this further development of the content takes place in close cooperation with experts. In addition to the further development, it is also essential to harmonize the use of the VR-based training system with the organizational and leading processes of the respective educational institution or training centre. As the results of the present study show, a corresponding briefing of the users, but also ongoing support and ongoing feedback from the trainers, must be ensured.

It is important to emphasize that many of the described difficulties were often expressed by individual participants. This makes it clear that problems when dealing with VR training can often be of individual nature. Therefore, it seems important to deal with the individual requirements with consideration and caution when introducing VR training. In summary, the case study was able to show a clear added value that results from the use of a VR-based learning environment for the learning experience in education and training.

All but one participant stated that they could imagine using VR training in education and training. However, the use of VR for orientational tasks should be further examined. The table 6.1 offers a brief summary of the key points regarding the opportunities and challenges in relation to the first research question.

	Opportunities	Challenges
Accessibility	Safe way of practising at own pace and with more repetitions. More confidence when first practising in VR, less fear of mistakes. Symptoms of cybersickness are very rare.	Individual differences or cybersickness can still cause problems, but good tutorial, support and getting familiar with VR beforehand helps to prevent these issues.
Learning	Better focus, fewer distractions, training of procedures and complex scenarios requiring combining and applying knowledge. Similar way of movement and relative position of objects to body promotes better recall.	The risks might be taken less seriously in the VR training scenario. Trainers might have difficulties learning how to use the system in the class.
Acceptance	The majority of the participants (>70%) were satisfied with the training, (>85%) said the training was fun, and all but one said they can imagine having similar trainings in their education. Overall high presence, hedonic and pragmatic quality and low cybersickness indicate a high acceptance accordingly to TAM [Dav89].	Finding motivated trainers and directors at vocational schools willing to put VR training into practice and possibly participating as experts in the development process might be challenging.
Motivation to Use	Fun, novelty, better focus, practical hands-on experience without needing more equipment than the HMDs with scenarios. Low fear of mistakes and their consequences, safe space for practice.	Extra organizational effort for vocational schools and trainers, additional costs of the equipment and scenario development so as maintenance. The precision of the haptic feedback is insufficient for some tasks. High realism and sufficient detail of visual cues is necessary.

Table 6.1: Summary of the opportunities and challenges in relation to the RQ1.

6.2 Recommendations

Based on the discussed challenges and opportunities, guidelines are formulated in this section, addressing the following research question:

RQ2: How can single-user VR HMD training be effectively and efficiently used in professional training, and which guidelines should be followed when designing and applying the training in a real-world context?

1. When designing scenarios for VR training, user-centred approach should be chosen, and experts and stakeholders should be involved in the consecutive stages of development process to guarantee relevance and correctness the of learning content. Future users should be invited to test the system beforehand to help to identify possible problems from their perspective.

2. The training scenario should implement various levels of difficulty to provide an optimal learning experience and motivation for all users, being not too easy nor too difficult. To increase realism and response to errors, the scenario should implement a direct feedback method.

3. The training system should be based on state-of-the-art technology to provide a satisfying user experience and presence. High realism and sufficient detail of visual cues is necessary.

4. Single-user VR training is particularly suitable for the training of procedural skills, especially for practising safety-relevant procedures. Also, complex scenarios in which different knowledge must be brought into context and applied correctly amplify the advantages of VR technology, since such scenarios are difficult to practise in the classroom or lab. Users have to actively deal and interact with the environment in order to learn effectively.

5. Especially in the beginning, the VR training should be supervised by a trainer who offers guidance if needed. First, an introduction on how to use the technology and setting the training goals are necessary. During the training, the user should have the opportunity to ask questions and get help when encountering difficulties. The training session should end with receiving feedback. However, the feedback and supervision do not necessarily have to come from the trainer, the VR training can also be done as a group exercise. Users who are already advanced might also practise the learning content independently and more frequently.

6. To prevent problems and difficulties when first using VR training, users should have the opportunity to try out the virtual environment in advance. This approach can preclude the occurrence of cybersickness and lower the levels of stress and frustration.

7. Before integrating VR training into curricula, a comprehensive guide on how to use the technology, including hardware and software, should be established. For this purpose, video tutorials are suitable and save the trainers time explaining the scenario.

8. The responsibilities regarding the maintenance of the VR equipment should be clearly defined to prevent technical problems.

9. For successful integration, the training must have a fixed place in the curriculum but should not fully replace already existing practical exercises. However, the exact form of integration should be let upon the trainers and vocational schools.

10. In order to ensure efficient and effective training, the trainers themselves should be expert users and be able to provide help if needed. Whether trainers with domain knowledge should be educated to lead the training, or external experts should be invited, depends on the specific characteristics of the training, its context and the decision of respective educational institution.

6.3 Limitations

Since this work focuses solely on the short term use of single-user VR training prototypes, it is beyond the scope of this work to draw conclusion about long term effects of using similar single-user VR training, therefore further longitudinal studies on this topic are needed. The study was conducted in the context of vocational education in Austria, therefore some points might not apply for different educational systems.

Since the DigiLernSicher field study was not supervised continuously, it was challenging to reach out to the apprentices during the study, resulting in lower answer rates on the second and third questionnaires. The participants were also not following the advice to always use the ID when starting the scenario, instead, they would sometimes pass the HMD directly to the next participant, resulting in problems with calibration of the HMDs and making the scenario logging data unusable for the study. In addition, due to the COVID-19 regulations regarding mandatory wearing of FFP2 masks, the comfort of the VR training system and problems with tarnished glasses might be affected.

CHAPTER 7

Conclusion

7.1 Conclusion

This case study examined the added value as well as requirements and possible challenges of single-user VR training in professional education from the perspective of future users and trainers. For this purpose, three training scenarios were implemented in VR and evaluated using a mixed-methods approach combining different survey methods: questionnaires, interviews, observations and task related data. These scenarios were tested with users absolving professional education in the respective field - 109 electrician apprentices worked with a scenario requiring to check possibly damaged electric installations in a flat, a group of 41 nurses practised laying out medical instruments for intubation on a medical trolley and in a next scenario practised a way-finding task to investigate if hospital evacuation training would make a suitable VR training content. Design-relevant aspects such as presence, user experience including pragmatic and hedonic values, so as technology acceptance were analysed in each scenario and compared. Furthermore, it was examined how the use of VR-based training in real contexts of vocational schools and training facilities was perceived by the participants and trainers.

The examined VR training scenarios enable the users to safely practise at their own pace with more repetitions. Also, practising in VR before performing the task in the real environment leads to higher confidence, less stress and less fear of mistakes. Individual differences and cybersickness can cause problems, however, providing a good tutorial, support during the training, and the opportunity to get familiar with the VR environment and ways of interaction beforehand can obviate cybersickness symptoms, feelings of frustration and, in general, improve the system accessibility. Better focus, fewer distractions, and the training of procedures and complex scenarios requiring combining and applying knowledge from different areas are the main identified advantages of learning with VR. On the other hand, the absence of error consequences might lead to the scenario being taken less seriously during the training, therefore realistic error feedback should be implemented. Fun, novelty and better focus are the most frequently mentioned motivational factors for using the system. The participants enjoy the hands-on experience of the VR training and see similar trainings as an enrichment of the current curricula. Nonetheless, integrating such training comes with organizational effort and requires additional costs. The highly positive feedback from interviews and questionnaires, especially the pragmatic and hedonic quality, together with perceived ease of use and usefulness, combined with a low occurrence of the cybersickness symptoms suggest a high level of acceptance among users. The majority of the participants were satisfied with the training, enjoyed it, and stated they could imagine doing similar trainings in their education. This study was supported by motivated trainers and directors of educational institutions who were interested in the new technology. However, it might be challenging to find similarly enthusiastic partners for future VR training. Also, the new learning approach might be challenging for teachers and trainers, who need to learn how to use it and integrate it into their lessons. Finding motivated partners willing to put such systems into practice is crucial. Therefore, increasing the awareness of what such systems can and cannot do and offering opportunities to test such systems are helpful for introducing them to a broader audience of users.

A user-centred approach is the key when designing training scenarios for VR training applications. Stakeholders, experts and future users should be involved in the various stages of development to give continuous feedback from various perspectives. Consecutively, the scenarios should be tested with a diverse group of users before deploying the system, to make the system accessible to all future users. In order to guarantee a satisfying user experience and presence, the training system should utilize state-of-the-art technology and provide a high level of realism. A comprehensive guide on how to use the technology is necessary and serves both the trainers and the students. Video tutorials are a suitable way of introducing the system to the users in the beginning, reducing the work load for the trainers. Regarding integration into the curriculum, the maintenance responsibilities must be clearly defined, and the VR training should have a fixed place in the curriculum, however not fully replace existing practical exercise. In addition, the trainers supervising the session must know the system well, and be able to provide guidance and help if needed. For effective learning, the scenario must require the user to actively deal and interact with the environment.

The results of this work can be used by organizations thinking about or planning to integrate single-user VR training in their educational programmes. The findings and recommendations for the design, integration use of future VR trainings can be used for orientation, comparison and prevention of difficulties during the process. Other projects can build upon the presented findings, deepen them and focus on specific design features and varying ways of implementation and integration. Further thoughts regarding the study-related topics are described in the following section.

7.2 Future Work & Outlook

This study shows that VR training is well suited for the training of procedural skills and the application of complex contextual knowledge, however, further research is needed to investigate other application areas. Moreover, the use of virtual reality in professional training in the long term should be examined, including the learning outcomes and knowledge retention over a longer period of time. It should be tested, if learning effects change over time and depend on how advanced the users are. Some users encounter difficulties at the beginning of the training, but at the same time, the novelty effect might have an influence on their perception of the VR training.

Since eye-tracking was used in a rather experimental way, further studies are needed to uncover the effects of the different design of VR training scenarios on the way of remembering and performing the learned task. Future VR solutions might also implement collaborative multiuser and gamification approaches, so as AI based solutions for altering the difficulty of the individual training scenarios, to better match the proficiency of the user. Since haptic feedback and fine motor movements are a problematic area in the VR training, more precise methods of interaction, such as gloves with sensors, might be examined and utilized. Also, VR technology brings an opportunity in using logging data from the scenarios, such as time, position, relative position of objects and sequence of actions, and allows details to be studied.

APPENDIX A

Appendix

Question (English)	Question (German)	Answer option
What is your gender?	Was ist Ihr Geschlecht?	List: female, male, no statement, other (Text input)
How old are you?	Wie alt sind Sie?	Integer
What training are you doing now?	Welche Ausbildung absolvieren Sie gerade?	Text
In which year of your training are you currently in?	In welchem Jahr Ihrer Ausbildung sind sie jetzt?	Integer
What is your highest degree of education?	Was ist Ihre höchste abgeschlossene Ausbildung?	List: mandatory school, apprenticeship qualification, high school diploma, university degree
How much experience do you have with VR or AR?	Wie viel Erfahrung haben Sie mit Virtual Reality oder Augmented Reality?	5-point Likert scale
How often do you play computergames/videogames?	Wie oft spielen sie Videospiele / Computerspiele?	Scale: never, less Once a month 1-3 times a month 1-3 times a week Almost every day

Table A.1: Demographic questionnaire used in DigiLernSicher and XRTrain projects.

I like to occupy myself in greater detail with technical systems.	Ich beschäftige mich gern genauer mit technischen Systemen.	6-step Likert scale
I like testing the functions of new technical systems.	Ich probiere gern die Funktionen neuer technischer Systeme aus.	6-step Likert scale
It is enough for e that a technical system works, I don't care how or why.	Es genügt mir, dass ein technisches System funktioniert, mir ist es egal, wie oder warum.	6-step Likert scale
It is enough for me to know the basic functions of technical systems.	Es genügt mir, die Grundfunktionen eines technischen Systems zu kennen.	6-step Likert scale

Table A.2: The Affinity for Technology Interaction short questionnaire used in DigiLern-Sicher and XRTrain projects.

How confident are you that you can pu into practice what you learned in the VR training?	Wie sicher sind Sie sich, dass Sie das, was Sie in diesem VR-Training gelernt haben, in der Praxis umsetzen können?	5-step Likert scale
If one of the situations trained with this system occurs in practicce, I will be able to master it better.	Wenn eine der mit diesem System trainierten Situationen in der Praxis eintritt, werde ich diese besser meistern können.	5-step Likert scale
Thanks to the training, I will be able to handle challenging situations more confidently in the furutre.	Dank des Trainings werde ich mit fordernden Situationen künftig sicherer umgehen können.	5-step Likert scale
After your experience with the VR training, how do you assess the usefulness of additional VR training in the apprenticeship?	Nach ihrer Erfahrung mit dem VR Training, wie schätzen sie die Sinnhaftigkeit von ergänzendem VR Training in der Ausbildung ein?	5-step Likert scale

Table A.3: The perceived quality of learning questionnaire used in the DigiLernSicher study.

The VR training was fun.	Das VR-Training hat Spaß gemacht.	7-step Likert scale
I encountered difficulties during VR training.	Ich habe während des VR-Trainings Schwierigkeiten gehabt.	7-step Likert scale
I felt frustrated during VR training.	Ich habe mich während des VR-Training frustriert gefühlt.	7-step Likert scale
I felt comfortable during VR training.	Ich habe mich während es VR-Trainings wohlgefühlt.	7-step Likert scale
The VR training is easily accessible for me.	Das VR-Training ist für mich leicht zugänglich.	7-step Likert scale
I am satisfied with the VR training.	Ich bin mit dem VR-Training zufrieden.	7-step Likert scale
It was easy for me to learn how to use the virtual environment.	Es war einfach für mich, die Nutzung der virtuellen Umgebung zu erlernen.	7-step Likert scale
I think the virtual environment is easy to use.	Ich finde, die virtuelle Umgebung ist komfortabel zu nutzen.	7-step Likert scale
I find the virtual environment easy to use.	Ich finde, die virtuelle Umgebung ist einfach zu benutzen.	7-step Likert scale

Table A.4: Technology acceptance questionnaire used in DigiLernSicher and XRTrain.

1	What did you find positive about the training, what worked well?
2	What did you find negative about the training, what did not work well?
3	Did you have any difficulties during the VR training? If yes, which?
4	Were you satisfied with the VR training? Why? Why not?
5	Do you have any suggestions for improvement regarding VR training?
6	Would you like to complete VR-based training in education and training? Why?
7	In your opinion, how could VR training be integrated into training? (Would it make sense to use the VR glasses in the training center, at school or at home?)
8	What advantages do you see in using VR in training compared to conventional methods (frontal teaching, exercise in the training facility)?
9	What challenges or difficulties do you see in using VR in education?
10	How could trainers/instructors be involved with regard to VR training and what roles could they have?
11	Do you have any further suggestions?
1	Was empfanden Sie am Training positiv, was hat gut funktioniert?
2	Was empfanden Sie am Training negativ, was hat nicht so gut funktioniert?
3	Haben Sie während des VR-Trainings Schwierigkeiten gehabt? Wenn ja, welche?
4	Waren Sie zufrieden mit dem VR-Training? Warum? Warum nicht?
5	Haben Sie Verbesserungsvorschläge hinsichtlich VR-Trainings?
6	Würden Sie in der Aus- und Weiterbildung gerne VR-basierte Trainings absolvieren? Warum?
7	Wie könnten aus Ihrer Sicht VR-Trainings in der Ausbildung integriert werden? (wäre ein Einsatz der VR Brille in der Ausbildungsstätte, Berufsschule oder zu Hause sinnvoll?)
8	Welche Vorteile sehen Sie bei der Verwendung von VR in der Ausbildung im Vergleich zu herkömmlichen Methoden (Frontalunterricht, Übung in der Ausbildungsstätte)?
9	Welche Herausforderungen bzw. Schwierigkeiten sehen Sie bei der Verwendung von VR in der Ausbildung?
10	Wie könnten Trainer*innen / Ausbilder*innen hinsichtlich VR-Trainings eingebunden werden bzw. welche Rollen könnten Sie haben? (Feedback, Gemeinsames üben in der Gruppe)
11	Haben Sie noch weitere Anmerkungen?

Table A.5: The list of interview questions used in DigiLernSicher in German as they were asked and their translation to English.

1	What did you find positive about the training, what worked well?
2	What did you find negative about the training, what did not work well?
3	Did you find the training easily accessible?
4	Did you experience any difficulties during the VR training? If yes, which?
5	Were you satisfied with the VR training? Why? Why not?
6	Do you have any suggestions for improvement regarding VR training?
7	Would you like to complete VR-based training in education and training? Why?
8	In your opinion, how could VR training be integrated into training?
9	What advantages do you see in using VR in training compared to conventional methods (frontal teaching, exercise in the training facility)?
10	How could trainers/instructors be involved with regard to VR training and what roles could they have?
11	What should one pay attention to in order to make VR training accessible to all people in training?
12	How could trainers/instructors be involved in the VR training or what roles could they have?
13	Do you have any further suggestions?
1	Was empfanden Sie am Training positiv, was hat gut funktioniert?
2	Was empfanden Sie am Training negativ?
3	Empfanden Sie das Training als leicht zugänglich?
4	Haben Sie während des VR-Trainings Schwierigkeiten gehabt? Wenn ja, welche
5	Waren Sie zufrieden mit dem VR-Training? Warum? Warum nicht?
6	Haben Sie Verbesserungsvorschläge hinsichtlich VR-Trainings?
7	Würden Sie in der Aus- und Weiterbildung gerne VR-basierte Trainings absolvieren? Warum?
8	Wie könnten aus Ihrer Sicht VR-Trainings in der Ausbildung integriert werden?
9	Welche Vorteile sehen Sie bei der Verwendung von VR in der Ausbildung im Vergleich zu herkömmlichen Methoden (Frontalunterricht, Übung in der Ausbildungsstätte)?
10	Welche Herausforderungen bzw. Schwierigkeiten sehen Sie bei der Verwendung von VR in der Ausbildung?
11	Worauf sollte man achten, um das VR-Training allen Personen in der Ausbildung zugänglich machen?
12	Wie könnten Trainer*innen hinsichtlich VR-Trainings eingebunden werden bzw. welche Rollen könnten Sie haben?
13	Haben Sie noch weitere Anmerkungen?

Table A.6: The list of interview questions used in XRTrain in German as they were asked in the XRTrain interview and their translation to English.

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Glossary

ATI-S Affinity for Technology Interaction, Short Version [WAF19].

HCI Human Computer Interaction.

HMD Head Mounted Display.

IPQ Igroup Presence Questionnaire [Sch03].

N Sample Size.

SD Standart Deviation.

SSQ Simulator Sickness Questionnaire.

SUS System Usability Scale.

TAM Technology Acceptance Model.

UEQ-S User Experience Questionnaire, Short Version [SHT17].

VR Virtual Reality.

VRNQ Virtual Reality Neuroscience Questionnaire [KCDM19].

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