User Experience with the Technology of Virtual Reality in the Context of Training and Learning in Vocational Education

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Content

Abstract

In recent years, the technology-based world of experience, such as virtual environments, has been increasingly used in learning and working contexts. Even though diverse general potentials are attributed to them, we know little about the effects of learning and working with these technologies within the realm of teaching and learning research. In particular, many different research approaches deal with the design of virtual environments and user experience (UX).

The virtual reality (VR) technology, with its features of simulation, interaction, and gamification, as well as the various technical aspects of input and output for movements and feedback, provides learners in the VR training and learning environment with the perception of immersion, spatial presence, and flow experience. Based on the theoretical research findings in terms of the learning processes and the learning motivation, the design and development of a VR training and learning environment should adhere to the principles of the UX design and the didactical design.

This presented research focuses on the generation of an explanatory and description knowledge about user experience with virtual reality technology in the context of training and learning in virtual environments. Based on the current development of VR technology, as well as the significant application areas, two empirical studies on the user experience of learners and (prospective) teachers with different types of virtual reality technologies in the field of vocational education are conducted. To test the user experience in the virtual reality training and learning environment, several aspects related to the user experience will be analyzed, including usability of the application, spatial presence, learning motivation, and flow experience of the students.

The first experimental study involves the theory-based development and evaluation of the virtual learning and working environment (VILA) for the training of social competencies, specifically the competence of perspective taking, in the field of industrial services with the (prospective) service technicians in the commercial and technical fields (n = 62) and the university students in vocational and technical education (n = 72). The VR environment is facilitated with different virtual rooms, such as meeting rooms and auditoriums, and interactive functions, such as the presentation with a virtual wall projector. Additionally, the navigation with keyboard and mouse, as well as the communication within the group with the microphone and earphones in the headset, is also possible.

The second empirical study focuses on the theoretical and technical development, piloting, and evaluation of the virtual physical sensor laboratory (VPSL) on the current topic of "sensors of the motor vehicle" and supports the acquisition of competence in the physical basics innovative sensors related to vehicle technology. The evaluation is carried out with students (n = 145) at vocational schools. The virtual physical laboratory is compatible with a VR headset with the already integrated monitor, processor, speaker, and rotation sensors. The interactive controller with the rotation sensors facilitates the interaction with the objects in the virtual environment.

The findings of the two empirical studies indicate that participants perceive the virtual training and learning environment as generally positive in terms of the constructs of flow experience, spatial presence, learning motivation, and usability. In both evaluations, participants have a strong experience of the fluency of performance and the absorption by activity and find the difficulty of the tasks in the virtual environments moderate, which induces the flow experience. The highly perceived spatial presence in the virtual environments indicates that the participants in both studies are immersed in the simulated world. The evaluation of the learning motivation reveals that the learning content in VILA and VPSL is not closely related to the daily working or the examination in schools. Still, participants give high evaluations to the dimensions of perceived overloading, perceived competence, and intrinsic motivation. The analyses of the usability of the applications show that the applications are suitable for the learning task and the learning application is learnable, with some features that need improvement.

The findings of the structural model analyses show that the perceived spatial presence mainly determines the perceived flow in the training and learning environment of virtual reality, indicating that the designed virtual environments are effectively absorbing and immersing their users with high spatial presence experience and the spatial presence is one of the important constructs in designing of a virtual reality learning environment to evoke the flow experience. The studies also explore the relationship between the constructs of spatial presence, learning motivation, and usability, demonstrating the significant correlation between them. The user experience, technological aspects, as well as methodological-didactical aspects should be together taken into consideration for the design, development, evaluation, and implementation of the VR training and learning environments to achieve an optimal learning result.

Based on the literature review, the empirical studies, as well as practical experience in the development of the VR training and learning environments, the recommendations for the design, development, evaluation, and implementation of the VR training and learning environments are discussed. With regards to the further implementation of VILA and VPSL, the requirements from the technological, administrative, and didactical perspectives are discussed. The limitations in the current research, as well as the directions for further research, are outlined.

Keywords: vocational education, virtual reality, spatial presence, learning motivation, usability, flow, user experience

Zusammenfassung

(Abstract in German)

In den letzten Jahren wurden technologiebasierte Erfahrungswelten, wie z. B. virtuelle Umgebungen, zunehmend in Lern- und Arbeitskontexten genutzt. Auch wenn ihnen vielfältige Potenziale zugeschrieben werden, ist im Bereich der Lehr- und Lernforschung noch wenig über die Auswirkungen des Einsatzes dieser Technologien auf das Lernen und Arbeiten bekannt. Insbesondere gibt es vielfältige Forschungsansätze, die sich mit der Gestaltung virtueller Umgebungen und der User Experience (UX) beschäftigen.

Die VR-Technologie mit ihren Merkmalen der Simulation, Interaktion und Gamification sowie den verschiedenen technologischen Aspekten von Input und Output für Bewegungen und Feedbacks, ermöglicht Lernenden in VR-Trainings- und Lernumgebungen Immersion, räumliche Präsenz und Flow-Erfahrung. Basierend auf theoretischen Ansatzpunkten bezüglich des Lernprozesses und der Lernmotivation sollten für die Gestaltung und Entwicklung einer VR-Trainings- und Lernumgebung die Prinzipien des UX-Designs und didaktischen Designs berücksichtigt werden.

Die vorgestellte Forschung fokussiert die Generierung eines Erklärungs- und Beschreibungswissens über die Benutzererfahrung von Virtual-Reality-Technologien im Kontext von Training und Lernen in virtuellen Umgebungen. Ausgehend von der aktuellen Entwicklung der VR-Technologie sowie sinnvollen Einsatzbereichen wurden zwei empirische Studien zur Nutzererfahrung von Lernenden und (angehenden) Lehrenden mit verschiedenen Virtual-Reality-Technologien im Bereich der beruflichen Bildung durchgeführt. Um die Benutzererfahrung von virtuellen Lern- und Arbeitsumgebungen zu untersuchen, wurden verschiedene Aspekte, einschließlich der Benutzerfreundlichkeit der Anwendung, der räumlichen Präsenz, der Lernmotivation sowie des Flow-Erlebens der Lernenden, analysiert.

Die erste experimentelle Studie beinhaltet die theoriegestützte Entwicklung und Evaluation der virtuellen Lern- und Arbeitsumgebung (VILA) zum Einsatz in Trainings zur Förderung der sozialen Kompetenzen im Bereich der Industriedienstleistungen mit (angehenden) Servicetechnikern in gewerblich-technischen Domänen (n = 62) und Studierenden der Berufs- und Technikpädagogik (n = 72). Die VR-Umgebung besteht aus unterschiedlichen Räumlichkeiten, z. B. aus Besprechungsräumen und Auditorien, und ist mit interaktiven

Funktionen ausgestattet, z. B. einem virtuellen Wandprojektor für Präsentationen. Außerdem sind die Navigation mittels Tastatur und Maus und die Kommunikation innerhalb der Gruppe über Mikrofon und Kopfhörer im Headset möglich.

Die zweite empirische Studie fokussiert die theoretische und technische Entwicklung, Pilotierung sowie Evaluation des virtuellen physikalischen Sensorlabors (VPSL) zur Thematik „Sensoren des Kraftfahrzeugs“, welche den Kompetenzerwerb zu physikalischen Grundlagen innovativer Sensoren rund um die Fahrzeugtechnik unterstützt. Die Evaluation wird mit Studierenden (n = 145) an Berufsschulen durchgeführt. Das virtuelle physische Labor ist kompatibel mit einem VR-Headset mit bereits integriertem Monitor, Prozessor, Lautsprecher und Rotationssensoren. Der interaktive Controller mit den Rotationssensoren erleichtert die Interaktion mit den Objekten in der virtuellen Umgebung.

Die Ergebnisse der beiden empirischen Studien deuten darauf hin, dass die Teilnehmenden die virtuellen Trainings- und Lernumgebungen hinsichtlich der Konstrukte Flow-Erleben, räumliche Präsenz, Lernmotivation und Usability insgesamt positiv wahrnehmen. In beiden Evaluationen erleben die Teilnehmenden den Ablauf als fließend, gehen in der Aktivität auf und empfinden die Schwierigkeit der Aufgaben in den virtuellen Umgebungen als moderat, was ein Flow-Erleben begünstigt. Die starke wahrgenommene räumliche Präsenz in den virtuellen Umgebungen deutet darauf hin, dass die Teilnehmenden in beiden Studien in die simulierte Welt eintauchen. Die Auswertung der Lernmotivation zeigt, dass die Lerninhalte in VILA und VPSL nicht eng mit dem Arbeitsalltag oder den Prüfungen in der Schule verbunden sind. Dennoch gaben die Teilnehmenden hohe Bewertungen zu den Dimensionen wahrgenommene Überforderung, wahrgenommene Kompetenz und intrinsische Motivation ab. Die Analysen der Benutzerfreundlichkeit der Anwendungen zeigen, dass diese – mit ein paar verbesserungswürdigen Merkmalen – für ihren Zweck geeignet sind und der Umgang mit ihnen einfach erlernbar ist.

Die Ergebnisse der Strukturmodellanalysen zeigen, dass die wahrgenommene räumliche Präsenz hauptsächlich das wahrgenommene Flow-Erleben in virtuellen Trainings- und Lernumgebung bestimmt. Dies deutet darauf hin, dass die entwickelten virtuellen Umgebungen ihre Benutzer und Benutzerinnen mit hoher räumlicher Präsenzerfahrung effektiv „eintauchen“ lassen und die räumliche Präsenz eines der wichtigen Konstrukte bei der Gestaltung einer Lernumgebung in virtueller Realität ist, um ein Flow-Erleben positiv zu

stimulieren. Die Studien untersuchen auch Zusammenhänge zwischen den Konstrukten der räumlichen Präsenz, der Lernmotivation und der Benutzerfreundlichkeit und zeigen signifikante Korrelationen zwischen ihnen auf. Die Benutzererfahrung, technologische Aspekte und methodisch-didaktische Aspekte müssen für die Gestaltung, Entwicklung, Evaluation und Implementation von VR-Trainings- und Lernumgebungen berücksichtigt werden, um dadurch ein optimales Lernergebnis zu erzielen.

Basierend auf dem Literaturüberblick, den empirischen Studien sowie den praktischen Erfahrungen in der Entwicklung der VR-Trainings- und Lernumgebungen werden Empfehlungen für die Gestaltung, Entwicklung, Evaluation und Implementierung der VR-Trainings- und Lernumgebungen diskutiert. Im Hinblick auf die weitere Implementierung von VILA und VPSL werden Anforderungen aus technologischer, administrativer und didaktischer Perspektive abgeleitet. Limitationen der Untersuchungen sowie ein Ausblick für die weitere Forschung werden skizziert.

Schlüsselwörter: berufliche Bildung, Virtuelle Realität, räumliche Präsenz, Lernmotivation, Usability, Flow, Benutzererfahrung

摘要

(Abstract in Chinese)

近年来，以技术为基础的体验世界，如虚拟环境，越来越多地应用于学习和工作环境中。尽管该技术有广泛的潜力，但在教学研究领域，人们对这些技术的使用对学习和工作的影响知之甚少，特别是许多关于虚拟环境和用户体验（UX）设计的研究领域。

虚拟现实（VR）技术及其模拟性、交互性、游戏化等所有特征以及动作和反馈的输入输出等各种技术环节，为学习者在 VR 培训学习环境中提供了沉浸感、空间临境感和心流体验。基于学习过程和学习动机的理论，VR 培训学习环境的设计和开发应按照用户体验设计和教学设计的原则进行。

本研究立足于在虚拟环境的培训学习背景下生成虚拟现实技术的用户体验的描述性知识的研究。基于 VR 技术的发展现状及其有价值的应用领域，本文对职业教育领域不同类型的虚拟现实技术的学习者和（准）教师的用户体验进行了两项实证研究。为了检验虚拟现实培训学习环境中的用户体验，将从应用的可用性、空间临境感、学习动机和学生的心流体验等几个方面对用户体验进行分析。

第一个实验研究涉及基于理论的虚拟学习和工作环境（VILA）的开发和评估，用于训练工业服务领域的社会能力，特别是观点采择能力，对象是商业和技术领域的（未来）服务技术人员（n=62）和职业技术教育的大学生（n=72）。该 VR 环境具备多种不同虚拟空间，如会谈室和会议厅，以及一些互动功能，如虚拟墙投影仪演示。另外，还可以用键盘和鼠标导航，用耳机中的麦克风和耳机在小组内进行交流。

第二项实证研究主要是针对当前“机动车传感器”这一课题，对虚拟物理传感器实验室（VPSL）进行理论和技术开发、试点和评价，并帮助学生获取关于车辆技术创新传感器的物理基础的知识和能力。评估在职业学校的学生（n = 145）中进行。该虚拟物理实验室与已经集成了显示器、处理器、扬声器和旋转传感器的 VR 头盔相兼容。带有旋转传感器的交互式控制器促进了与虚拟环境中物体的交互。

两次实证研究的结果表明，在心流体验、空间临境感、学习动机和可用性等方面，参

与者对虚拟训练和学习环境的整体感知是积极的。在两次评价中，参与者对流程的流畅性和活动的专注性都有很强的体验，并认为虚拟环境中的任务难度适中，从而诱发了心流体验。虚拟环境中的空间临境感强，说明两次研究中的参与者都沉浸在模拟世界中。对学习动机的评价表明，VILA 和 VPSL 中的学习内容与学校的日常工作和考试关系并不密切。但学员对于学习过程中的内在动机，感知到的学习负荷以及自己的能力的评价很高。应用系统的可用性分析表明，应用系统在对任务的适用性和对学习场景的难易程度上评价较好，但有一些功能需要改进。

结构模型分析结果表明，空间临境感体验主要决定了虚拟训练和学习环境中的心流体验。这表明，所开发的虚拟环境能有效地让用户“沉浸”在空间临境感体验中，空间临境感是虚拟现实中设计学习环境的重要建构之一，能积极激发用户的心流体验。研究还探讨了空间临境感、学习动机和可用性三个结构体之间的关系，并显示出它们之间的显著相关性。在对虚拟培训和学习环境进行设计、开发、评估和应用时，用户体验、技术方面的建构以及教学法方法论都应该同时考量，以得到良好的学习效果。

本文在文献综述、实证研究以及 VR 培训学习环境开发实践的基础上，提出了对 VR 培训学习环境的设计、开发、评价和实施的建议。关于 VILA 和 VPSL 的进一步实施，也从技术、管理、教学等方面的要求进行了讨论。本文概述了目前研究的局限性，以及进一步研究的方向。

关键词：职业教育，虚拟现实，空间临境感，学习动机，可用性，心流，用户体验

List of Included Publications

1. Guo, Q. (2020). User Experience Design und Evaluation in immersiven Virtual-Reality-Umgebungen. In B. Zinn (Ed.), Virtual, Augmented und Cross Reality in Praxis und Forschung: Technologiebasierte Erfahrungswelten in der beruflichen Aus- und Weiterbildung - Theorie und Anwendung (pp. 31–55). Franz Steiner Verlag.

2. Guo, Q., Ditton, B., & Zinn, B. (2019). Eine Anwendung der Virtuellen Realität in der beruflichen Bildung im Kontext physikalischer Lerninhalte. In: Sandra Schulz (Ed.), Proceedings of DELFI Workshops 2019 (pp. 173–186). Gesellschaft für Informatik e.V.z. DOI: 10.18420/delfi2019-ws-119.

3. Zinn, B., Guo, Q., & Sari, D. (2015). Entwicklung und Evaluation der virtuellen Lern- und Arbeitsumgebung VILA. Journal of Technical Education (JOTED), 4 (1), 89–117. https://www.journal-of-technical-education.de/index.php/joted/article/view/71.

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List of Abbreviations

VR	virtual reality
AR	augmented reality
MR	mixed reality
XR	extended reality
TVET	technical and vocational education and training
ICT	information and communications technology
UNESCO	united nations education, scientific and cultural organization
UNESCO-UNEVOC	international centre for technical and vocational education
CLI	command-line interface
NUI	natural user interface
TUI	tangible user interface
VILA	virtual learning and working environment
VPSL	virtual physical sensor laboratory
HUD	heads-up display
HMD	head-mounted display
UX	user experience
UI	user interface
VILA	virtual learning and working environment
VPSL	virtual physical sensor laboratory

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1. Introduction

1.1. Virtual reality technology in teaching and learning

In the industrial as well as vocational and academic fields, training and learning based on computer science and internet technologies are increasingly popular applied and studied (Zinn, 2017), such as distance learning, blended learning, flexible learning, and other approaches that can enhance the quality of TVET (Technical and Vocational Education and Training) programs and expand the access to TVET programs. Various digital elements, including text, voice, images, videos, simulations, animations, and interactions, have already become part of many users' learning processes. Among the ICT (Information and communications technology) applications for training and learning, virtual reality is gaining popularity in modern vocational education thanks to its features of real-time visualization, simulation and interaction in a virtual world. With the development of 3D immersive technology, the immersive interface in a 3D environment enables training and learning in safe, convenient, and more controlled environments (cf. de Otero, 2019a).

In terms of the global strategy for vocational education and training, the implementation of virtual reality is considered to be helpful. In the Strategy for Technical and Vocational Education and Training (TVET) (2016-2021) of United Nations Education, Scientific and Cultural Organization (UNESCO), UNESCO will support to leverage digital technologies and harness the promise of the ICT revolution to ensure more comprehensive sustainable development benefits (cf. United Nations Educational, Scientific, and Cultural Organization, 2016). In the UNESCO-UNEVOC (International Centre for Technical and Vocational Education and Training) virtual conference with the theme Innovation in TVET in 2019, the benefits of incorporating virtual reality into educational practices were also discussed: the virtual reality learning engagement as a tool for increasing access to TVET could enhance the effectiveness and quality of the TVET as well as result in easier application and retention of the subject matter (cf. de Otero, 2019b).

From the perspectives of both domestic development of vocational education and training as well as international cooperation, virtual reality is also regarded as meaningful support for the development of industries. In October 2014, the governments of Germany and China co-chaired the third round of intergovernmental consultations in Berlin under the theme "Innovative Cooperation", starting the new generation of Chinese-German cooperation. In the Action Outline for the Chinese-German Cooperation, "Cooperation in Industry 4.0" is one of the sub-sections of "Sustainable economic development and cooperation in the financial field", indicating that the digitalization of industry, which is the primary subject of Industry 4.0, plays a crucial role in the economic development of both countries, and that both governments should offer policy support for companies to participate in the revolution process.

In May 2015, based on the plan of industry digitalization and inspiration from the German Industry 4.0, the Chinese State Council unveiled the project "Made in China 2025"[1] in order to raise the level of competitiveness through automation and technology, combining information technology and industrial technology. Under the industrial revolution, with its instantaneous changes in production and manufacturing, it is fundamental to pay attention to the training of the competencies of the person occupying the role in this virtual working environment. In the context of "Industry 4.0", the future requirement for employee competence has changed immensely. Smart equipment and workers with technical expertise, as well as the competencies of planning, coordination, evaluation, and decision-making, will gradually take the place of machine operators along the assembly line. A transfer of the competence requirement will take place from the specific working ability to a composite of competencies. Sustainable employee competence development will also be taken into account because of the multidisciplinary and interdisciplinary nature of smart manufacturing (cf. Zinn, 2019). Therefore, the major challenge of the development of Industry 4.0 would modernize the system of vocational training in order to meet the corresponding growing skills demands. Even some employees with years of working experience at the assembly line may lack sufficient knowledge of the internal structure and functional principles of the manufacturing equipment.

The "High-Tech Strategy 2025" published by the Federal Government of Germany indicates that virtual reality and other innovative technologies with friendly usability and user experience of human-machine-interaction should be implemented for the future technological competencies of the qualified workers. The digitalized training is meaningful for the "Education in sustainable development" with innovative instruments and methodologies (cf. Bundesministerium für Bildung und Forschung, 2018).

[1] Official website: http://english.www.gov.cn/2016special/madeinchina2025/, date retrieved: 11.22.2019.

The "National Industry Strategy 2030" published in November 2019 by Federal Ministry for Economic Affairs and Energy Germany indicated that the German industry benefits in particular from the factors including the training and working in the dual training system. For the training of the workforce, vocational training and further education in the dual education system should be modernized concerning the digitalization of the industry. The promotion of new technologies in training and learning in vocational education is necessary for people to get ready for the change. Training and learning in virtual reality correspond with the requirement for the competence development of the technical working world with the goal of life-long and inclusive learning (cf. Bundesministerium für Wirtschaft und Energie, 2019).

The enhancement of the quality of vocational training is in line with the need to support the development and prosperity of "Industry 4.0". The high-tech, internet-driven, and networked era supports the homo interneticus to adapt new learning approaches. The initiative "Vocational Education 4.0" by the Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, 2017) supports the digital transformation in vocational education and training. Since 2016, the Federal Ministry of Education and Research has been accelerating the digitalization of training centers for vocational workers. Till summer 2019, there are nearly 200 training centers equipped with edging technologies or theoretical training, including the implementation of virtual reality glasses and remote controlling technologies (cf. Bundesministerium für Bildung und Forschung, 2019). Of all the components of vocational training, learning and training in a mixed reality system may be the most virtualized, providing the possibilities to train under challenging working or training conditions, to improve training quality, and to reduce the occupational health and safety risks (cf. Bosché et al., 2016).

1.2. Research objectives and approach of the research

From the author's perspective, the foundation of a training and learning scenario in virtual reality includes mainly three facets, the development of VR technology, the implementation of learning theory, and the design with user experience principles. The three dimensions together form a training and learning scenario. The theoretical parts of this thesis will be structured from the three dimensions, leading to empirical studies in the following chapters. This is only a simplification of the fundamentals in teaching and learning scenarios since the other perspectives are not viewed in-depth, such as the teachers and learners in the teaching and learning process, the training and learning content, and other viewpoints.

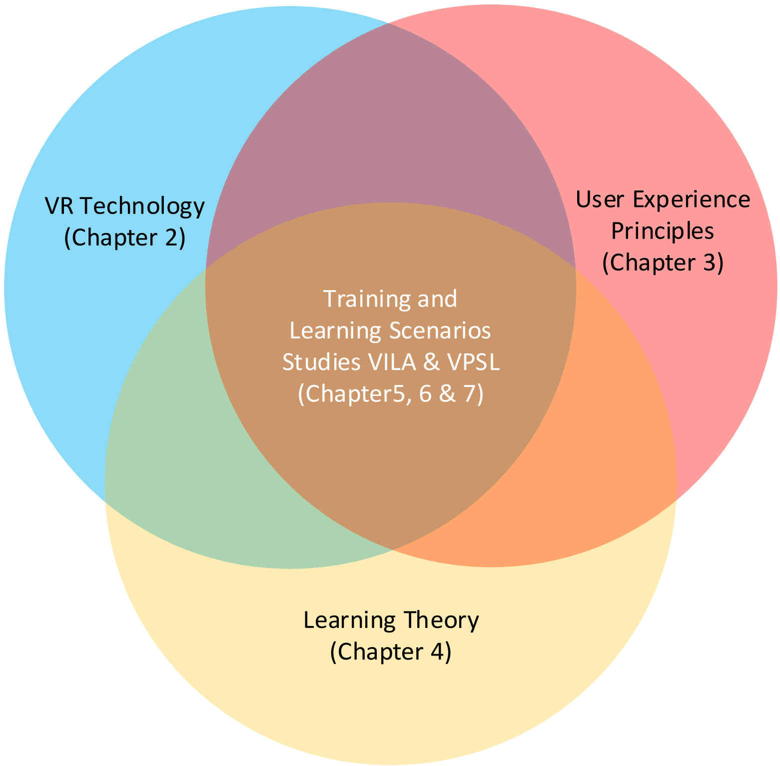

Figure 1-1 Three theoretical aspects of the thesis (source: own presentation)

To create an immersive environment for learners, an appropriate set of hardware and software could be useful. For example, a head-mounted display (HMD) is considered to be a suitable device to create an immersive environment. Moreover, a careful set-up virtual environment consisting of all the teaching and learning elements with proper strategies and decorations will be necessary for the students to enjoy the immersive experience (cf. Schuster et al., 2017). The detailed description and consideration of the application of the technology will be presented in Chapter 2.

Considering the implementation of new technology in the educational field, it is necessary to discuss the user interface, usability, and user experience throughout the learning and teaching process. The term "user experience" indicates the whole interactional experience of the users before, during, and after utilizing the product and includes all kinds of feelings of the users, especially those presented by virtual reality such as immersive presence, motivation, usability as well as the flow experience of the users (cf. Guo, 2020). A detailed discussion of the user experience will be indicated in Chapter 3.

From a didactical perspective, the learning process in the virtual reality environment is mainly controlled by the students themselves, which, as declared in the Bologna Declaration, is essential for students to develop their employability. According to Salzman's studies, immersion in virtual reality can advantage education in at least three ways, by enabling multiple perspectives, situated learning, and knowledge transfer, which are typically fulfilled by the shifting between an exocentric and an egocentric frame of reference with varying strengths for learning (cf. Salzman, Dede, Loftin, & Chen, 1999). In the framework of the project "Excellent teaching and learning in engineering sciences (ELLI)", Schuster's study (2015) of learning in virtual theatre shows that immersion in virtual environments with natural user interfaces does not lead to better learning outcomes than the virtual desktop interface, which is, however, limited to learning outcomes in a maze game, which could be not suitable to learn in virtual reality. In general, computer simulations offer our education the possibility to change perspectives and to make difficult situations accessible to the students. A further discussion of the didactical implications of virtual reality will be discussed in Chapter 4.

Based on the theoretical research in the preceding chapters, Chapter 5 indicates the research questions of the subsequent empirical studies, the hypotheses for the analysis, as well as the study design. In Chapter 6 and Chapter 7, two empirical studies are conducted based on the recent literature review and practical experiences, focusing on the research topic of the impacts of spatial presence, usability, and motivation on the flow experience of the learning participants. The two empirical studies focus on the generation of descriptive knowledge about the user experience with virtual reality technology in the context of training and learning.

Although virtual reality could support constructivist education in many ways, there is still a lack of research addressing the issue of "How virtual environments enhance learning outcomes" rather than "Do virtual environments enhance learning outcomes" (cf. Lee et al., 2010). If virtual reality is to be used to support professional learning, then it is necessary to examine the relevant important constructs to help to achieve this goal. Several researchers have conducted a few studies on this topic. Lee et al. (2010) proposed a conceptual framework of the outcomes in a desktop VR-based learning environment based on Salzman's model (1999), in which the entire learning procedures are divided into three parts for the empirical model: income, process, and outcome. Motivation, as a psychological factor, is found in the process part of this model and has been studied extensively. One of the assumptions of the cognitive motivational theories is that motivation is not one's stable character but inherently malleable depending on the context of learning (cf. Linnenbrink & Pintrich, 2002). In virtual reality with immersive interface and interaction, motivational value has its research justification.

Based on the literature review and practical experience, the virtual reality technology for large-scale vocational education is mainly represented by the desktop-based VR environment and the immersive VR environments. Therefore, a desktop-based VR environment is examined in Study I, and an immersive VR environment is tested in Study II. The hypotheses about the user experience knowledge in the virtual reality learning scenarios are tested in both studies. The research objectives in Study I are firstly the descriptive analysis of social demographic data, studying and working interest, learning motivation, spatial presence, the usability of the application, as well as flow experience in the desktop-based virtual training and learning environment (VILA). In addition to the description of the constructs of the user experience, the relationship between the constructs is analyzed in order to exam the correlation between the constructs as well as the influence of the spatial presence, usability, and learning motivation on the flow experience. The descriptive and statistical analysis of VILA would give an overview of the learning experience of collaborative training and learning of social competence in the desktop-based virtual environment. In Study II, the learning experience constructs of learning motivation, spatial presence, usability, and flow experience, as well as the demographic situation, are evaluated with an immersive virtual reality environment as a virtual physical sensor laboratory (VPSL). The descriptive, correlative and structural model analysis is conducted to measure the perception of the learners in the learning sessions and the relationship between the constructs.

In Chapter 8, the summary of this dissertation will be presented as well as the limitations of the work that need to be improved. The implications and future research directions are also discussed. The following diagram (Figure 1-2) depicts the structure of this thesis.

Chapter 1: Introduction

- 1.1 Virtual reality technology in training and learning
- 1.2 Research objectives and approach of the research

Chapter 2: Virtual Reality Technology for Learning

- 2.1 History of virtual reality
- 2.2 Virtual reality and its features
  - Definition
  - Simulation for teaching and learning
  - Interaction and interactivity
  - Gamification and serious game in VR-applications
- 2.3 Technical aspects of learning environment in virtual reality
  - Input for head movement and output for visual feedback
  - Input for body movement and locomotion
  - Input for hand gestures and output for haptic feedback
- 2.4 Consideration of the application of VR
  - Simulation technology
  - Ethical aspects
- 2.5 Interim conclusion to virtual reality technology for learning

Chapter 3: User Experience in Virtual Reality

- 3.1 Usability
- 3.2 User interface and user interface designs
- 3.3 User experience and its constructs
  - Immersion
  - Spatial presence
  - Identities, avatars and characters
  - Narrative sTorytelling
  - Flow
- 3.4 UX Design: iterative and agile development
  - Requirements analysis and concepts design
  - Prototypes and evaluation methods
- 3.5 Interim conclusion to user experience in virtual reality

Chapter 4: Learning in Virtual Reality

- 4.1 Learning processes in VR
  - Behaviorism
  - Cognitivism
  - Constructivism
  - Embodied cognition
- 4.2 Learning motivation in VR
  - Definition of learning motivation
  - Components of learning motivation
- 4.3 Didactical design in VR
  - Learning in computer-mediated environments
  - Learning software
- 4.4 Interim conclusion to learning in virtual reality

Chapter 5: Research Questions and the Conception of the Empirical Studies

- 5.1 Research questions and hypotheses
- 5.2 Overview of the design of the empirical studies

Chapter 6: Study I: An Empirical Study with Virtual Reality with Traditional Interface

- 6.1 Research background
- 6.2 Experimental design
  - Environmental setups
  - Training content
  - Training procedures
  - Methodology
- 6.3 Results of Study I
  - Descriptive analysis
  - Structural model analysis
  - Results of the questions about VILA
- 6.4 Discussion of Study I

Chapter 7: Study II: An Empirical Study with Virtual Reality with Immersive Interface

- 7.1 Research background
- 7.2 Experimental design
  - Environmental setups
  - Learning content
  - Training procedures
  - Methodology
- 7.3 Results of Study II
  - Expert review
  - Descriptive analysis
  - Structural model analysis
- 7.4 Discussion of Study II

Chapter 8: Discussion and Conclusion

- 8.1 Summary
- 8.2 Limitations of the research and VR application
- 8.3 Implications and future research

Figure 1-2 Structure of the thesis (source: own presentation)

2. Virtual Reality Technology for Learning

Virtual reality technology is not one single type of technology but includes the facets of user motion tracking, real-time interactions, image rendering, wide-angle display, and other new technologies, that are essential in the development of creating virtual immersive and interactive learning environments, as will be discussed in this chapter in detail.

2.1. History of virtual reality

The topic of virtuality and reality could ascend to ancient times. The Greek philosopher Plato used the Allegory of the Cave to emphasize the effects of education in his The Republic, indicating the world we see may be only a projection of the real world. The name “Cave” from Plato was referenced later in the 1990s when the cave automatic virtual environment was built as a room-sized immersive virtual reality equipment. The concept of virtual reality was shown in scientific novels in the 1930s (e.g., Brave New World by Aldous Huxley, 1931), in which man can wear glasses to immerse oneself into a virtual world with all senses: smell, taste, and touch.

The combination with technical applications starts in the middle 1900s. In 1953, Bwana Devil came to the world. The first color 3D film impressed the majority of the audiences, followed by a series of 3D films on the market, such as House of Wax. In 1957 American director and photographer Morton L. Heilig invented sensorama, the 3D sensorama machine to watch movies with comprehensive and peripheral vision, motion, stereo sound, aromas, and vibrations, Sensorama marked the beginning of the development of virtual reality (cf. Heilig, 1960; 1962). It was called “the cinema of the future”. From then on, the development of virtual reality has never stopped from the perspective of military applications and laboratory applications.

In 1968, Ivan Sutherland invented a pioneering virtual reality system with a head-mounted display and head position sensors, named “The Sword of Damocles”, because of the appearance of the system (cf. Sutherland, 1965; 1968). In the 1980s, a plethora of virtual scientific movies and innovative products appeared to the public. Then in recent years, the public’s attention has shifted back to virtual reality with the advancement of information technology. In 1985, Jaron Lanier, a computer philosophy writer, computer artist, as well as a pioneer in the field of virtual reality, founded the company VPL Research, whose products were the first virtual reality data gloves, virtual reality gear, virtual reality glasses, and the full-body data suit. After that, there are implementations of concepts of virtual reality like movies or novels coming to market each year with a wild imagination and the inspiration of the future technology, ranging from The Matrix (1999) to Ready Player One (book: 2011; film: 2018).

2.2. Virtual reality and its features

2.2.1. Definition[2]

One of the great characters of applications of the virtual reality system is the part where it is mixed with actual reality based on different kinds of applied interfaces and presenting forms, which is likely to be named mixed reality in many kinds of literature. Mixed reality, a mix of reality and virtual reality, refers to the broad area of continuous transition between the two extreme ends, physical reality to virtual reality (cf. Milgram & Colquhoun, 1999). The continuum relationship between RE (Real Environment), AR (Augmented Reality), AV (Augmented Virtuality), and VE (Virtual Environment) is shown in the following figure (cf. Milgram & Colquhoun, 1999). At the left end of the continuum is the real environment (RE), which would be training in the traditional classroom, laboratory, or working onsite in the context of vocational training. However, the inevitable restrictions would be an occupation of time and space of onsite project equipment, not to mention the occupational health and safety risk. On the right side of the continuum is the virtual environment (VE), enabling training to proceed in an environment with all the artificial sensory experiences such as sight, touch, in addition to immersion and spatial presence. Steuer (1992) argues that presence is the core element of a virtual reality system, which will be discussed in the following sections.

According to Milgram and Colquhoun (1999), when some virtual elements are imported into a real-world environment, we have augmented reality (AR), which is reality augmented by virtual elements. For example, the transparent interfaces of a head-mounted display (HMD) can support the training and even implementation of complex maintenance tasks (e.g., Google Glass and Microsoft Hololens) by showing the electronic information on the transparent screen, allowing the user to view both virtual and real information concurrently, such as virtual route markers on the real road or individual electronic information beside the real products (e.g., AR furnishing application IKEA Place). By the end of 2015, an augmented-reality massive

[2] A part of this section was published in Guo (2015).

multiplayer game "Ingress" with the online map and allocation technology has gained millions of players. Through the "Ingress" application, players can view the virtual gaming information about actual objects and architectures around the screen of mobile phones. From a development perspective, there are tools available for developers to create content in the AR environment. For example, the AR development platforms of Apple, with the frameworks of "ARKit" and "RealityKit", also provide numerous creation tools for the users or developers to create interactive AR experiences with their hardware products.

Vice versa, when some real-world elements are imported into the virtual environment, we have augmented virtuality (AV). For example, a real CNC (Computerized Numerical Control) platform can be connected with a virtual production line to train the steering and management of the CNC control platform (cf. Blümel et al., 2010). In terms of the comparison of virtual reality and augmented reality, VR is a fully immersive and enclosed experience (Oculus Rift), while AR is similar to wearing a transparent mobile phone on the face (Hololens). Augmented reality and augmented virtuality differ mostly from each other on the point of the ratios of real-world elements versus virtual modeled elements in the display that people view, and also whether the environment is real or virtual (cf. Milgram & Colquhoun, 1999).

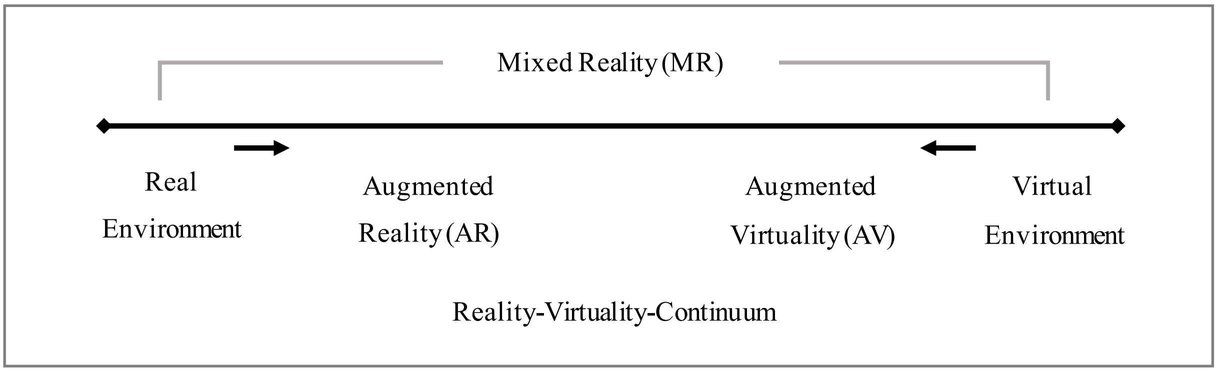

Figure 2-1 Reality-virtuality-continuum (cf. Milgram & Colquhoun, 1999)

There have been numerous additional discussions about the definitions, especially with the development and combinations of the technologies, such as virtual retina displays, haptic data gloves, motion detectors, eye-tracking sensors, and other monitoring and tracking system. The term "Cross Reality" or "Extended Reality" (XR) indicates the fusion of the technologies of "the ubiquitously networked sensor/actuator infrastructure", that is "endemic to pervasive computing", and "the massively shared online virtual worlds" with the 3D virtual environments (cf. Paradiso & Landay, 2009). The "Cross Reality" refers to the technological implementation of rendering and manifesting phenomena between real-world and virtual environments, affecting both systems meaningfully and discernably (cf. Coleman, 2009; cf. Lifton et al., 2009).

Based on the model of Milgram and Colquhoun (1999), Mann et al. (2018) extended the dimensions of MR and proposed "Multimediated Reality" ("All Reality") as a superset of mediated, mixed, augmented, and virtual reality. The defined "multidimensional multisensory mediated reality" includes "not just interactive multimedia-based reality for our five senses, but also additional senses as well as our human actions/actuators". The referred "Multimediated Reality Continuum" includes many axes such as "Reality", "Virtuality", "Phenomenality", "Digitality", and other dimensions, some of which may be complex-valued, not desirable or combined with other dimensions (cf. Mann et al., 2018).

Mixed Reality is gaining popularity in modern vocational training thanks to its real-time visualization, simulation and interaction in a virtual world. One of the practical examples in the construction training field would be excavator training, in which trained operators have been shown to be more efficient than traditional method-trained operators at the beginning of their real-life work (cf. Wallmyr et al., 2019). Another example would be the construction assistance tool developed in a VR project by the University of Twente, which focuses on the development of visualization of communication and training methods to acquire new working knowledge (cf. Vasenev et al., 2011).

One of the main infrastructures of a mixed reality learning system is the web-based learning environment where the collaboration of students can be realized regardless of time or location whether synchronously or asynchronously (cf. Wang & Chiu, 2011). This can be seen in the case of the Java-based open source project Darkstar by the company Sun[3], in which virtual collaborative offices and conference rooms are built for both working and training. Although the project was discontinued following the acquisition of the company, it was beneficial for vocational training using a mixed reality system. Nowadays, virtual collaborative working spaces are required by more companies than before. Although the video conferencing systems help the routine team meetings, many companies started to utilize the virtual working space for the social meetings and catch-ups of the employees, keeping the positive elements of the real-

[3] Sun Microsystems, Inc. was an American IT company and acquired by Oracle Corporation in 2010, http://www.oracle.com/us/sun/index.html.

office environment, such as the serendipity of the in-person interactions (e.g., the platform Spatial[4]). In the VR field, the collaborative learning settings with immersive HMDs are still not cost-effective, and in the early development phase, that multiple learners and teachers with immersive HMDs in the virtual settings collaborate for the learning scenarios. Therefore, the collaborative aspects of this research would be represented in the study with desktop-based VR learning and working environment. In the study with the immersive VR technology, the collaboration of the students is represented in the cooperation of the quiz-solving tasks, their protection of the team members, as well as their assistance with the new technology.

In the application field of vocational training, for example, construction engineering students can learn to build a house together, and interior design students can discuss the decoration of any house or apartment. Together with institutions and companies from six European countries, the Sustainability Research Center (ARTEC) at the University of Bremen developed a mixed reality learning system "Virtual Laboratory in Mechatronics: Access to Remote and Virtual E-Learning (MARVEL)" for the vocational training of students in mechatronics to support the ubiquitous remote access to the physical workshops and laboratory facilities, combining a local and remote, real and virtual environment (cf. Müller & Ferreira, 2004, p. 66). Based on the web-based collaborative mixed reality system, collaborative learning and working are some of the focuses of MARVEL research. Compared to isolated learning and working, group collaboration is closer to real-work situations, with the functions of improving the non-technical soft skills of students such as social communication skills, foreign language ability, intercultural competence, and customer orientation (cf. Müller & Ferreira, 2004). In the project of MiRTLE (mixed reality teaching and learning environment) at the University of Essex, the students dispersed across the mixed reality classroom are able to see the avatars (3D models in mixed reality representing the animations of actual users in a virtual environment) of others and interact with others, building a connection between physical reality and mixed reality (cf. Alzahrani et al., 2015; cf. Gardner & Sheaffer, 2017).

Given the high cost of remote lab equipment, a further research project (cf. Müller & Schaf, 2009) developed a mixed reality system of collaborative remote laboratories (CORELA) as a simple and inexpensive method to support engineering education, with which students can access a real programmable logic controller (PLC) both locally and remotely.

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[4] Spatial is an AR/VR platform for meeting and collaborating with holographic avatars. https://spatial.io/

Moreover, a carefully constructed mixed reality environment consisting of various suitable learning elements with proper strategies and decorations will be necessary for the students to enjoy the immersive experience as well as acquire the knowledge (cf. Schuster et al., 2014). The overarching aim of an appropriate design in a mixed reality system would be to match the users' characters (e.g., age, pre-existing knowledge). In this case, the mixed reality learning system from Shanghai Jiao Tong University was developed with a Data Analysis Center, which collects and analyzes the process data from teaching and learning in the log files of web-servers to enable the further development of the learning system, including students browsing online courses and querying course materials (cf. Callaghan et al., 2010, p. 270).

With the rapid evolution of information technology, the concepts of modern "teaching" and "learning" are clearly changing and, across time and context, will move from "multimedia learning", via "e-learning", to "learning in a mixed reality system".

2.2.2. Simulation for teaching and learning

In the face of educational practice, the teachers with various tools often take advantage of simulations of learning content to impress the students to enhance the learning interests or to explain the objects in a non-real context in a better way. The technology of computer simulation has been developed for education and training - not only for large and complex systems such as the economic system (company management), the ecological and geological system (climate change and GIS, short for Geographic Information System), the social system (city constructions and city management) and the scientific system (outer space and underwater system) but also for sophisticated micro-processes like medical training, manufacturing control, finite element structural analysis and geometry (cf. Bosch et al., 2015; Deng et al., 2009; Huang et al., 2015; Kamphuis et al., 2014; Kerres, 2012; cf. Lin et al., 2013; cf. Lin et al., 2015; Tolio et al., 2013). In the early stage of research of simulation and virtual environment, Dörner (1976) proposed and categorized the characters of simulations into two groups, environment characters including complicity, dynamic, network, and sedateness, as well as behavior characters including reversibility, cost dependency, time dependency and location dependency (cf. Dörner, 1976; cf. Dörner & Schaub, 2002).

Simulation can be used in many educational and training cases (cf. Höntzsch, 2013). From the view of ergonomics, the simulation may reduce the risk of causing errors or harming the health, in the worst case causing the death of the learner or others (cf. Höntzsch, 2013). For example, the result of analysis of the mechanical working system situation indicates that learning or training in a real mechanical working environment is often limited by incalculable, irreversible, and even sometimes impossible risks (cf. Blümel et al., 2010).

From the view of availability, the simulations of virtual reality environment have the advantages that the non-existed or hard-to-get situations can be simulated, extending the limitation of learning environments, such as motions underwater, in the outer space or on the moon, by manipulating the physical coefficients like gravity and environment damping, which meets their kinesthetic expectations, as well as the sense of hearing, seeing and feeling (cf. Bosch et al., 2015). The learning sessions are set around the simulated environments.

In addition, the situation in the past or in the future can be simulated in order to present the formation or evolvement of the object. For example, one of the studies by Mosaker (2001) shows the simulation of historical sites and the processes of cultural evolution. Portman et al. (2015) review the simulations of architecture, landscape architecture, and environmental planning, which are mostly inaccessible realities, prompting the improvement to achieve various levels of virtual reality. A promising product in the realm of the GIS would be the Google Earth VR, which provides the controls of simulations of walking-around in a selected city, flying in the air above the ocean and browser the other sites in the world.

From the view of didactics, it is essential for learners to visualize the real-time interactions and relationships between objects and states. The various points of view (POV) of the users that in VR the camera mainly defines afford the user to observe and feel the virtual world from the unique points of views, such as the view of another user or an animal and the view of an atom in a small scale. For example, a virtual model of generators and other equipment are built in the projects of Fraunhofer IFF (Fraunhofer Institute for Factory Operation and Automation IFF). With the virtual models whose parts can be transparent or deleted temporarily, students can clearly get to know how the inside functions and elements connect to each other, how they can better maintain the equipment, as well as the assembly and disassembly of the equipment (cf. Blümel et al., 2010).

Industrial simulation, the simulation of the realistic industry, could be one of the practical ideas to enhance development efficiency and to reduce the risk of the company. The application of industrial simulation can be in any part of the production, including reports, designs, sales, market promotion, after-sale service, and website. In terms of employee training, the industrial simulation promotes the activity and enthusiasm of employees, which in turn enhances the efficiency of training.

With the development of the hardware and the possibilities of realistic and reasonable interactions, the experience in VR turns from the scenarios with pure imitation and traditional perception of the objects to the interaction with the surroundings, which leads to the tacit practical knowledge and immersion presence experience. One of the fascinating factors of virtual reality is not only the possibility to copy a real but difficult-to-be environment, but also the possibility to have some anti-physics but reasonable factors, such as opening an instructional brochure with a button and changing the color of a car with a color-picking panel. The VR is not a real world, but a magic world that seems real. The whole VR environment can be seen as the interface of user interaction. So the consideration should be taken on how the comfortable interface for the interaction would be. There are a lot of unrealistic and surreal elements in VR, but logic is always essential. The distraction happens if the virtual environment is not as real as the real environment or if the virtual environment is not as logical as the real environment.

Lighting is an essential aspect of the perception of the VR environment and the presence experience. In the immersive user experience design, recreating such light patterns like in the physical world is difficult, but the researchers in computer science and graphic processing put efforts into it and offer the solutions of head-based rendering a realistic environment (cf. Akenine-Möller et al., 2018; cf. Mihut et al., 2018; cf. Slater et al., 2009). Lights and shadows are the keys to realizing the virtual but realistic world. By moving the objects or their own hands and bodies, the users convince themselves of being in a real world with the parallel moving of their shadows. The setting of the scenario in VR has more power over the users than the normal 2D environment. The closure or openness of the virtual environment would influence the emotions and feelings of users. The art piece “NowForeVR” by the artist group The Swan Collective (2018) presented how the mixed lightning techniques could combine 3D animation and painting to create an immersive virtual environment.

The integration of the 360-degree camera into the simulation process to build the virtual content and the virtual environment gives us another perspective to mix reality and virtuality. 360-

degree photography has already been in many fields applied, such as in education and tourism[5], due to its immersive experiences.

360-degree-videos can be taken with 360-degree cameras, also known as omnidirectional cameras, with one or more lenses with a large field of view. The different main feature from the ones of normal 2D-videos is that 360-degree-videos are equirectangular videos, and the viewer could look at all the directions in the video from the point of the camera after the editing processes. The editing process works mainly for the merging of recorded clips on all the lenses on the 360-degree camera into a fully spherical panorama video. The video editing software provides the function of transition, cutting, editing as well as exporting the videos into a suitable format for the application with VR headsets.

The 360-degree videos could be watched on a two-dimensional monitor, such as a mobile apparatus or computers, with the possibility of rotating the view of the audience with a mouse, the gravity sensors of mobile phones, or other input equipment. However, the 360-degree video brings more immersive feelings to the audience if it is viewed omnidirectionally with a VR headset because the recipients could be isolated from the real physical environment and immersed in the recorded remote location (cf. Mazmanyan, 2020).

The combination of 360 Videos and VR technology gives a more immersive and realistic experience in VR, which could be beneficial in many application situations compared to computer-generated visualization and simulation. The immersive situation of 360-degree videos with VR technology draws on the concept of embodied cognition (4.1.4 Embodied cognition) by supporting the re-experiencing of the classroom settings and responses virtually at that time and space and stresses the theory of situated learning in the perspective of constructivist (4.1.3 Constructivism) by inviting the video viewer as active participants in the learning process. Therefore, it has implications for broader vocational teaching and learning.

In the practice of pre-service teaching training, video reflection has been used as an effective tool for self-development and peer evaluations. Using the 360-degree video instead of the "classic videos" could avoid the disadvantages of "classic videos", such as missing the

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[5] For example, the firm GSK launched in 2019 the application "360 ° Swiss Heritage" for the tours in three Swiss castles with virtual reality glasses, desktops, or mobile phones (https://www.360-swiss-heritage.ch/).

important elements outside the camera perspective and the subjective influence of the person holding the camera on the chosen camera perspectives and the condition of teaching and learning persons (cf. Windscheid & Will, 2018). The study to evaluate the 360-degree videos in training the student teachers using the think-aloud protocol and interviews indicates that the immersive and embodied experience provides a more nuanced understanding and of the microteaching practice and supports the self-efficacy towards the teaching of the student teachers (cf. Walshe & Driver, 2019). Compared to watching the “classic videos”, the students could observe the whole class or focus on individual pupils for more details for their reflection (cf. Walshe & Driver, 2019). The application of the technology of 360-degree camera is limited, as with other innovative technologies, due to the sample size of the video clips, possible camera positions, delivered video quality as well as integration into the interactive VR technologies.

Compared to the computer-generated VR environment, 360-degree videos offer less freedom in terms of navigation and interactions in the virtual environment. The user with the VR headset watching the 360-degree videos could only watch the scenario passively. However, the addition of active interactions and movement could be realized by integrating other information through the hotspots (cf. Mazmanyan, 2020). By interaction with the hotspots, the users call out the animated 3D models, text, graphics, or sounds developed or integrated with other technologies other than videos, such as 3D-modelling, 3D-developing, and 3D-sound-recording. Through the hotspots, the users could also change to the next scenarios or video clips, which gives the same effect as teleporting in the VR environment. There is also the technical exploration in the transformation from a 360-degree photograph to a 3D model in the field of visualization (e.g., the mapping technology by NavVis[6]). Examples of 360-degree-videos for building tours and vocational training are not uncommon, such as the training of cooking (e.g., Koopmans Professional Academy online training courses[7]) and the tour in a technical center (e.g., Google Data Center 360° Tour[8]).

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[6] NavVis provides mainly the mapping technology from the 360-degree photograph+ to 3D-model of a building (https://www.navvis.com/).

[7] Koopmans Professional Academy gives the training of cooking with 360-degree videos (https://www.koopmans-professioneel.nl/koopmans-professioneel/academie/online-training).

[8] Google Cloud Team provides the Google Data Center 360° Tour with a building tour, interviews with the designers and developers as well as the introduction of technical efforts of the data center (https://cloud.google.com/blog/products/gcp/google-data-center-360-tour).

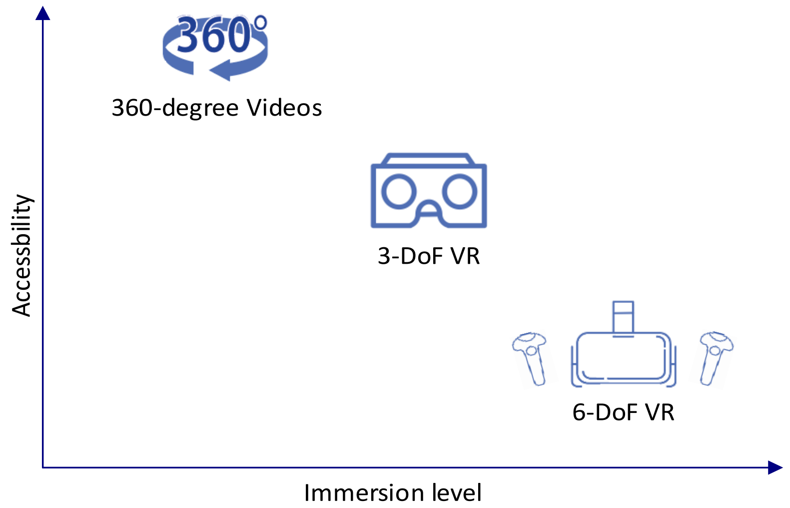


Figure 2-2 The immersion level and the accessibility of the various technologies (source: own presentation)

In the teaching and learning settings with 360-degree videos, the focus of the video is one of the challenges in virtual reality. Because the user could look around without the pre-set focus of the video, the attention of the users could be misallocated, and the goal of the learning process would not be succeeded. Therefore, the design of the audio, the looking direction, and the movement of the actors in the learning scenario should take the focusing movement of the users into consideration.

In the industry and manufacturing areas, two crucial technical factors for the realization of a virtual learning environment may be the precision of visualization of knowledge and the precision of interactions among humans and objects (cf. Pan et al., 2006). The resolution level of the virtual element, the speed level of the data transmission, and the accuracy level of system reaction are valued as the key points of technical parts from the perspective of the users' experience. In order to create an authentic environment, the setting of both hardware and software should include physical coefficients such as environment damping, rigid body dynamics, kinetics interactions between user and objects, as well as interactions among objects. In a virtual world, the force system should be consistent, including gravity, the force of friction, acceleration, other capabilities, and constraints in physics. The design of UX in virtual reality could use reality as a reference. The pioneer developer of VR, Myron Krueger, suggested that VR is only virtual physics (cf. Hansen, 2006). In the framework proposed by Jacobson (2017), authenticity refers to "the relationship between truth and its representation, guided by a purpose". The purpose of the learning experience and the learning content indicates what kind of truth or realistic representation is needed and which affordances should be captured, which leads to the concept of the level of details., describing the action, motion, and the appearance of the virtual environments (cf. Jacobson, 2017). In the projects of Fraunhofer IFF, virtual models of generators and other equipment are built (cf. Haase et al., 2014). The authentic and dynamic animation in a virtual environment can facilitate spatial understanding and compensate for the low ability of spatial recognition ability according to the research of Münzer (2012, 2015). With respect to the illustrations of learning content, the empirical research of Magner et al. (2014) on the decorative illustrations in computer-based learning environments postulates that the decorative illustrations have positive motivational effects on knowledge transfer by fostering situational interest, but charming illustrations should be excluded from learning system (cf. Magner et al., 2014).

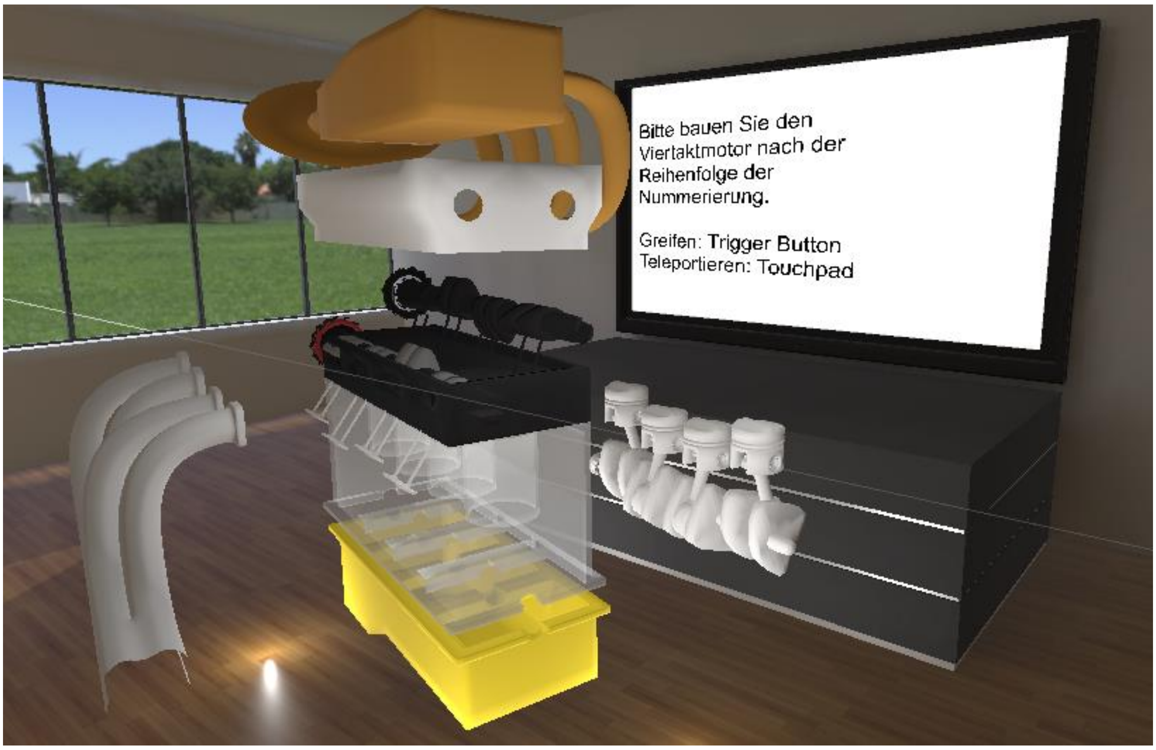


Figure 2-3 The learning scenario of the assembly of a four-stroke engine (source: own presentation)

An example of the simulation and animation of the learning scenario would be the assembly of an automobile four-stroke engine, designed and developed by the author (Figure 2-3). The students in the virtual room could learn the components of a four-stroke engine and assemble them, following the tutorial on the virtual screen and the pop-up hints. With the visual feedback and vibration feedback from the controllers (HTC Vive), the users could experience an immersive experience during the learning procedures. The same as other applications with HTC Vive, the teleportation, the interaction with controllers as well as the navigation with real walking are integrated into the user experience.

Diversified ideas can be realized on the 3D models with both the authenticity of real objects and the possibility of reconstruction, which is one of the significant advantages of a mixed reality system. With students transferring from passive participants to active contributors, cooperation in a mixed reality system has positive effects on idea expression, material sharing, task collaboration as well as the development of situational interest.

On the contrary, the obstacles of simulation in some cases may be too much authenticity when the user has less experience as a starter in using a computer. In the real working environment, the task complexity is always one hundred percent, where reduction is not possible. However, in a virtual environment, the didactic reduction of the complex environment makes it possible to give the learners in different knowledge levels suitable forms of professional knowledge. When learning in a virtual environment, the irrelevant aspect of graphic representation would be avoided because of the specific tolerant limit of perception of learners (cf. Lindsay et al., 2009). Additionally, the debugging intention of the virtual environment and simulated materials may also hinder the learning process, whose solution may be the suspension of disbelief (cf. Vorderer et al., 2004, p. 3). As the VR literacy of the target users is just at the beginning, the complexity of the learning content, the relationships between the elements, and the interaction combination of the controlling operation would also increase.

In order to improve the learning process, appropriate didactic methods should be applied to the simulation of learning, which will help to build the relationship between the new knowledge and the existed experience of students (cf. Schuster et al., 2017).

2.2.3. Interaction and interactivity

Human-object interaction in a mixed reality system enables students to take control of avatars, which are present alongside the real or virtual objects in the learning environment. The interaction is companied with instant feedback built on the complex network and data computing, offering the students a bright and vivid sense of the learning content with multiple aspects, such as in experiments on mechanical models and structures in the mixed reality system. Psychological training and testing can be done under the conditions of a mixed reality system. After the input of precise programming, an avatar (simulated human in a mixed reality system) can be not only a participator in the technologically created world but also an instructor, an evaluator, or an observer as an experiment conductor. The change of roles between VR and users inspires more possibilities in the future virtual reality industry (cf. Kelly, 2017).

In most of the operational learning subjects, laboratory exercise plays a fundamental role in building student knowledge, that is one of the practical substitutions of on-the-job training because it is possible for students to have a haptic experience of the learning content of subjects rather than only theoretical knowledge building (cf. Morrison et al., 2011). The development and application of mixed reality for learning and experimenting environments emerge and become necessary, where most of the limitations of real, local experiments can be omitted with the help of simulation and interaction of a mixed reality system. The cooperation and interaction of humans and robots can be used to realize an intelligent and smart factory. In the same way as the programmed robots in the smart manufacturing process, programmed objects and interactions with objects in a mixed reality training system not only have the advantages of the realization of objects that are not easily accessible but also have the ability to imitate various applied situations.

During the process of learning, based on the learning process and instant feedback from students, it is possible for the mixed reality system to adjust and modify the content and difficulty of current or later tasks, enhancing the effectiveness of learning and keeping the students interested in learning. The users adapt their abilities of reading, cognifying, and learning to the new scenarios. This is evident in the mixed reality game engine Unreal Tournament developed by Cavazza et al. (2002, p. 17) as the development environment of an interactive storytelling application. The technology of intelligent virtual actors enables story generation based on user intervention, supporting the convergence of traditional and interactive media. Consequently, each individual has his or her own learning procedures with compatible competence and learning interest, ensuring a better transfer process than a traditional learning situation with one teacher and numerous students. An appropriate learning procedure is also a critical factor in maintaining learning interest. Interactions can not only be performed between humans and virtual objects but also be simulated between humans and virtual animals. The training of proper treating animals can be realized without threatening the health of animals or human beings.

The immersion of the virtual world comes with a deep sense of interaction. The productions of VR films start to give the audiences a new sense of movie experience. Taking the film Henry (director: Ramiro Lopez Dau, 2015) as an example, the Oculus Story Studio[9] created a virtual environment where the users or audiences with 3D glasses could walk, talk, and interact with the objects in the movie to fulfill the sensations and to promote the plot. In this way, VR shows the ability to intense the narrative of a story by creating interactive experiences and providing the possibilities to explore.

The following figure shows an example of possible interactions in an immersive learning environment with a 6-DOF[10] virtual reality interface. In the introduction scenarios for the beginners using an immersive VR training environment, the users have the possibility to explore the basic interactions with the objects, such as throwing, grabbing, and sliding the machine components on the tables, the presentation interactions, such as video and audio playing controlled by a panel, and the social interaction with a simulated avatar in the meeting room, who introduces the functions of the scenarios. The training process of the introductive course for the immersive VR environment is shown in the following flow diagram.

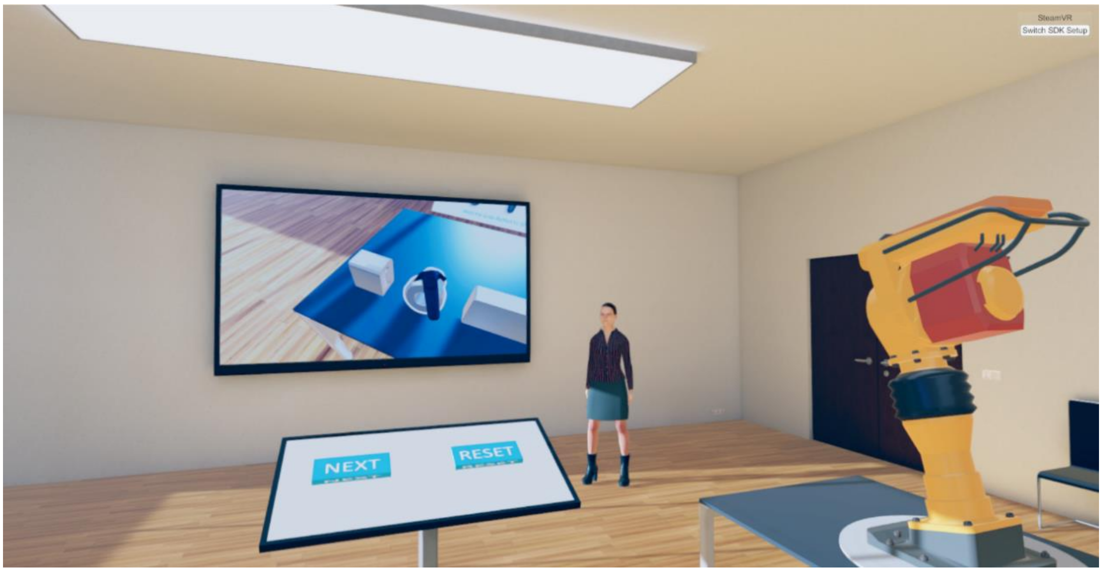


Figure 2-4 The VR environment of the training course of VR Introduction (source: own presentation)

[9] Oculus Story Studio is a department of the Company Oculus, which is one of the main producers of VR products.

[10] 3-DOFs (degrees of freedom) in VR environments refer to the tracking of the rotational movement around the x, y, z axes, and 6-DOFs in VR environments refer to the tracking of the rotational movement around the x, y and z axes as well as the tracking of positional movement along the x, y, z axes.

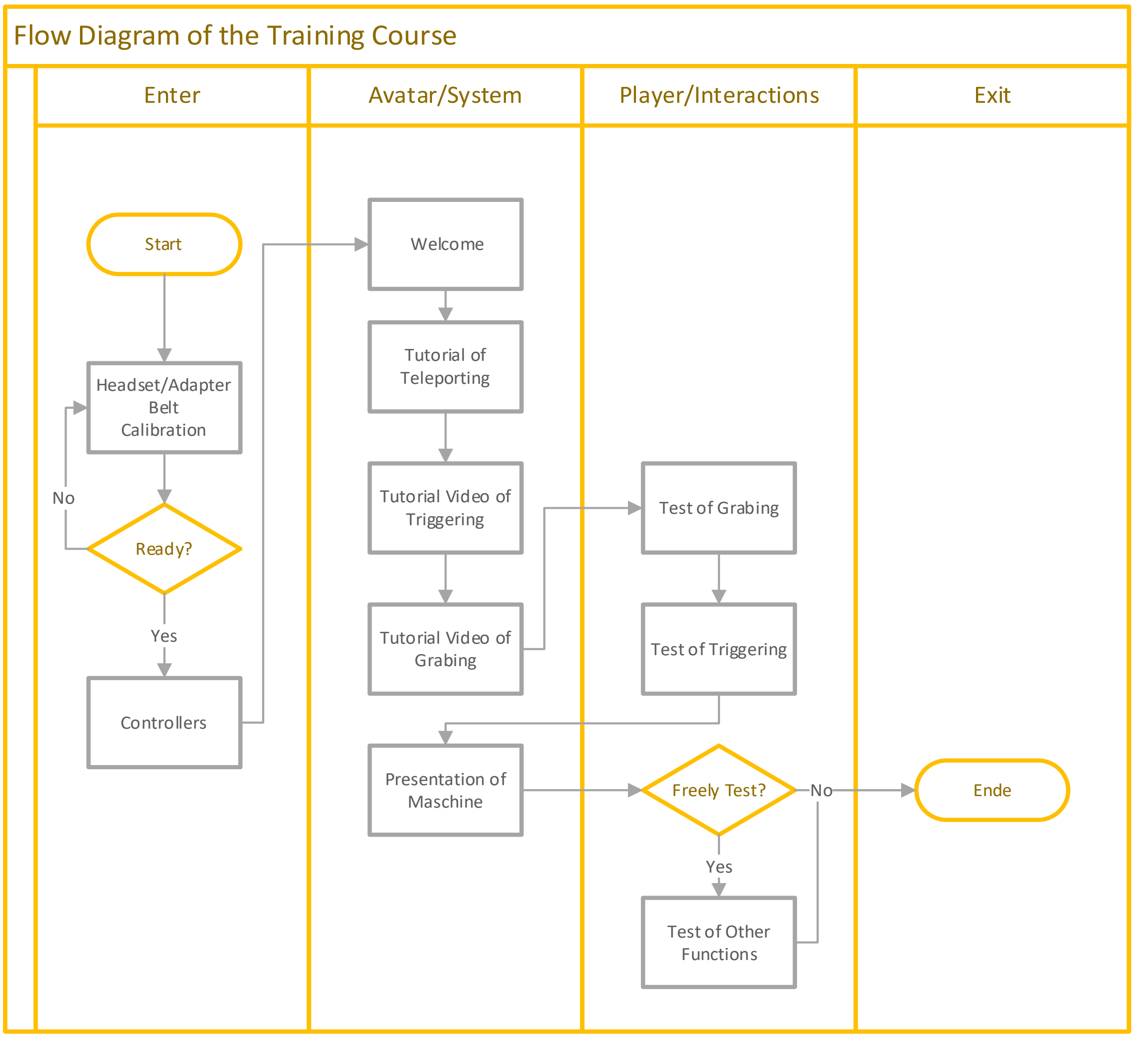


Figure 2-5 The flow diagram of the interaction in the training course of VR introduction (source: own presentation)

For now, the avatars in a mixed reality system can have the ability to perform almost all the body, gestures, and mimic movements of human beings. Except for the technical challenges of system reaction and delay resolution, these movements are vivacious and vivid. In addition, most movements required for teaching and learning procedures can be already performed on a laptop or PC with basic configurations.

2.2.4. Gamification and serious game in VR-applications

Computer and video games with active, self-controlling, constructive and situate learning characters are gaining popularity with the development of the adaptability to kinds of modern gaming platforms (e.g., browsers, tablet PCs, and smartphones). Sometimes video games may be notorious time wasters, with players ignoring all the other things and staying up all night to conquer the next level without noticing the learning process in the games. In recent years, the entertainment functions of virtual reality have been broadcasted, and most investors or producers are willing to benefit from the hardware and software related to virtual reality.

In one of the comprehensive studies of arcade video games, Sherry et al. (2006) isolated some factors of arcade games' uses and gratifications, offering insight into the appeal of arcade games, including competition, challenge, social interaction, diversion, fantasy, and arousal (cf. Sherry et al., 2006). Although the import of gamification in the context of learning and training has both advantages and disadvantages, these gaming factors have proved that they could be useful in the virtual learning context, namely, educational games or serious games (cf. Sherry et al., 2013; cf. Sherry, 2013). One of the standard features of game-based learning, educational games, or serious games is the intention to be "serious" or educational.

The serious game is a kind of game developed for application functions other than pure entertainment, which is also a developmental focus of a mixed reality learning system (cf. Callaghan et al., 2010, p. 262). In the 1980s, serious games were firstly developed for applications of teaching techniques, training, and simulation. With the realizations of analysis, visualization, and simulation, the serious game has included interactive applications not only related to education but also personnel training in the industry, policy discussion between governments, emotional training in the military, as well as health care and medical care. Nowadays, a significant trend of application of serious games in education has emerged, especially in the field of higher education. Online social communities (e.g., Second Life[11], OpenSim[12] , and Open Wonderland[13]) have been pervasive in the past ten years, where people can interact with other users after logging in. Users can build their own 3D mixed reality environment with the toolkits of the platforms. This has expanded its application area from gaming to learning. Universities across the world have built their own educational institutions in Second Life, including the University of Bielefeld, Saint Leo University, and Oxford University Computing Services. The aim of a serious game is not to make games serious but to expand to other research fields while maintaining the characteristics of games at the same time.

As is shown in the following graphic, compared to normal learning applications on the computer, the serious game has its own characteristics, gamification, which refers to the process of input

[11] More information about the environment: http://secondlife.com/

[12] More information about the environment: http://opensimulator.org/

[13] More information about the environment: http://openwonderland.org/

gaming ideas and gaming strategies into non-gaming contexts such as learning, training, and manufacturing, in order to improve the user experience and engagement (cf. Deterding, Sicart et al., 2011). As defined by Deterding, Khaled et al. (2011), the differences between gamification applications and serious games is to the extent that how much the gamified elements and non-playing elements are in the learning environment (cf. figure of definition of gamification, Deterding, Khaled et al., 2011). With respect to the educational training domain, it refers to the input of gaming ideas and strategies into the process of training for lasting and high learning motivation.

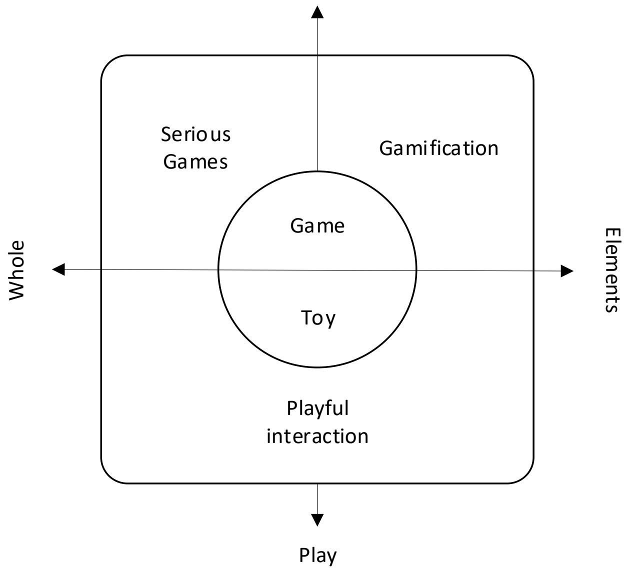


Figure 2-6 Definition of gamification (cf. Deterding, Khaled et al., 2011)

Self-efficacy is one of the important theories related to the application of computer games. The experience happens when the player gets a direct reaction from the virtual environment (cf. Le et al., 2013). Self-efficacy is “the extent of one’s belief in his or her ability to reach the goal or complete tasks” (cf. Bandura, 1977, 1993). When the participants have a feeling with frequent and transparent feedback that they have mastered the games and achieved the goals, they may have higher long-term motivation, which leads to a positive cycle.

The tension, some may result from the competition, is also effective in keeping students concentrated and motivated when the challenges and successes in the game playing are balanced. The negative results of the tension from the gamification elements would be the emotion of frustration and disappointment (cf. Le et al., 2013).

Regarding role-playing, one of the widely used methods of application of serious games on vocational training may be scenario tasks. Based on the concept of scenario, typical working tasks are developed as scenarios and scenario players, i.e., the trainees are trained with the steps of actions in the scenarios, which can be repeated over and over until the trainees have got the skills (cf. Blümel et al., 2010). Through these scenario-training tasks, interactive actions are set, and the actions are controlled by the learners. Therefore, in these scenarios, descriptive knowledge can be connected with procedural knowledge in terms of procedures of concrete working processes, for example, the elements of machines as well as the functions of these elements. These working or training steps can be either with direction or without direction. Instructions can be offered by the avatar or scenario system. However, in some situation s where the instructions and additional information are not necessary, the learners themselves can decide training steps (cf. Blümel et al., 2010).

Gaming elements and gaming strategies have been leveraged in the teaching process from kindergarten to higher education. However, mixed reality systems provide a larger view of gaming as well as training opportunities. For now, most mixed reality applications driven by financial benefits are mixed reality games, whereas learning in a mixed reality system with the trait of gamification will be a great trend of digitalized applications. The project of EPICSAVE builds a serious game environment with the simulation of the training of confronting emergencies for the students in Paramedics. The results of the pilot studies indicate that the specifically multi-user VR may enhance paramedic training (cf. Schild et al., 2018).

In this section, the development of the definition of virtual reality (VR) and the related concepts AR and MR are introduced, mainly within a reality-virtuality-continuum and the extended "All Reality" continuum (cf. Mann et al., 2018; cf. Milgram & Colquhoun, 1999). The most impressive feature of virtual reality would be the simulation, which has been utilized in many educational projects with teaching and learning scenarios in various majors and professionals. The simulation in a VR environment includes not only the virtual environment and the animated objects but also the lighting system, the interactions with the objects and the other individuals, as well as the physical environment with the pre-defined physical coefficients and the physical effects. One of the discussed topics in the implementation of VR in the learning field is the serious games and the features of gamification, which have been used with other computer-mediated applications. In summary, this section gives an overview of the main features of the technology of virtual reality with the potential and practical application in the training and learning field.

2.3. Technical aspects of the learning environment in virtual reality[14]

Learning applications in the virtual learning environment may include the following parts to realize the learning activities: Knowledge Space, Communication Community, Active Action, and Facility Toolkit (cf. Pan et al., 2006). Every VR platform, hardware, or software has its advantages, disadvantages, and suitable application scenarios. From the perspective of engineering, it is also an important researching focus to conquer the difficulties of both hardware and software and develop the appropriate VR equipment for users. From a commercial perspective, a great number of market opportunities are created by the manufacturers of virtual reality hardware, including the companies Avegant, Google, Oculus, Samsung, Virtuix, HTC, Sony, and other key vendors, as well as the software and the content production. In 2019, over $4.1 billion AR/VR investment was tracked (cf. Digi-Capital, 2020). Recently the company Apple confirmed the acquisition of the startup company NextVR (cf. Gurman, 2020), which provides the content for various virtual reality headsets, indicating the potential of boosting the VR marketing again since 2013, when Facebook bought the VR Startup Oculus. In addition to the standalone and console version of VR, modern smartphones with high-resolution displays, advanced sensors, and strong processors are possible to be the equipment of the realization of VR applications, leading to the development of the mobile-integrated VR headset. The combination of smartphones and VR headsets shows that it plays a crucial part in the market due to its ease of use, portability, and independence, such as the products Samsung Gear VR and Oculus Go with the integration of the Oculus VR technology and the product Daydream VR platform with the integration of the Google VR-platform.

In this section, the technical aspects will be discussed, including the perspectives of input for head movement and output for visual feedback, input for body movement and locomotion, input for hand gestures, and output for haptic feedback. Parts of the discussions have been published by Guo (2020), based on which the section gives a more comprehensive description of the technological aspects of the applications of virtual reality. It is not to judge whether a kind of technology is better than the other, but to discuss the suitable learning situations where the technology would be useful. Over the past decades, the improvement of VR technology has provided various innovative user interfaces between the human and the machine and blurred the line between reality and virtuality, which will be discussed in the following sections.

[14] Some paragraphs and illustrations in this section was published in Guo (2020).

2.3.1. Input for head movement and output for visual feedback

In terms of applications, intuitive control with instant input as well as feedback ensures less cognitive burden in VR from the control of the environment than in the non-VR environment (cf. Schuster, 2015). It is still necessary to investigate what kinds of technological features of the input and the output would benefit the learning experience of the learners in the immersive virtual reality environments.

In 1960, Heilig, who is "the father of virtual reality", invented the first virtual reality headset in the world named Telesphere Mask (cf. Heilig, 1960), replacing the traditional interfaces with mice and keyboards as well as monitor screens. It looks very similar to the virtual reality headset nowadays (e.g., Oculus Rift). After all these years, many of the technical obstacles have been conquered, and many of the technical challenges that Heilig mentioned are still here. From then on, the development of VR equipment has never stopped. The visual distribution in VR includes two main parts, the projectors and the head-mounted display (HMD).

A simple version of 3D simulation in the classroom teaching and learning would be the combination of 3D glasses and a 3D DLP (Digital Light Processing) projector, which also brings an extension of 2D representation to 3D visualization to some extent and offers the student the simulated information and experience (cf. Molnár & Benedek, 2015). The results of the research that took place in schools in seven countries in Europe and examined the learning strategies and teaching methods with 3D experiences in the classroom indicated that visual learning improved the pupils' understanding of the functionality and the pupils had a strong preference for visual and kinesthetic learning (cf. Bamford, 2013).

An advanced 3D projector could follow the motions and visual angles of users to create a view of an artificial environment, which is often used in industrial simulated training. A famous product of the 3D projector is the Cave Automatic Virtual Environment (CAVE), with the projector surfaces forming the virtual box. The input of the users in the CAVE includes head-tracking devices, hand tracking devices, and controllers, which ensure free motion in the virtual world in all directions as usual, vertical or horizontal (cf. Grimm et al., 2013).

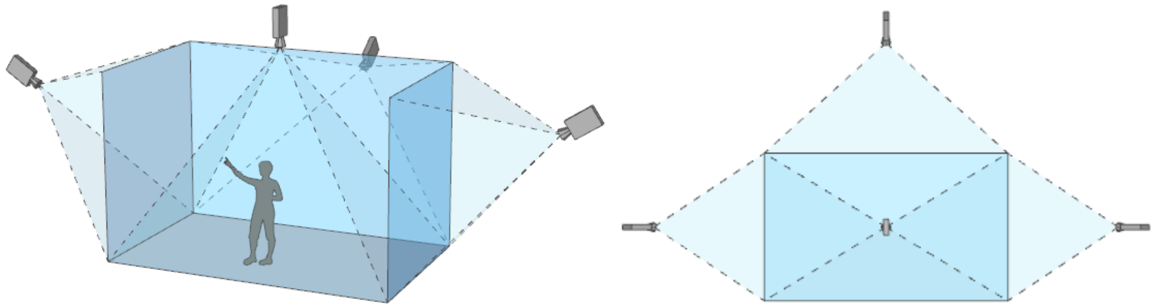


Figure 2-7 Illustrations of the projections in a Cave Automatic Virtual Environment (source: own presentation)

An advantage of CAVE would be that the motion sickness and discomfort in the eyes would be less than what the HMD headset brings. Additionally, in the CAVE VR environment, a user could see the real mimics and the body language of the other users in groups and get the real and direct reactions of the team working. The disadvantage of the CAVE is also clear. The disadvantages of CAVE are the limited field of view and unreal interactions with objects. Only one user controls the point of view, and the others have to follow along in the direction and position. They could not freely move or look within HMD. In this case, the view-followers would likely have motion sickness from moving around or changing views.

In addition to the projection-based visualization technology, a head-mounted display (HMD) is a visualization and interaction system, normally in the form of displays mounted on a helmet or data goggles fasten directly on the head. The output device generates the representation on the screen and delivers it to the users. The motion sensors detect the spatial position and movement of the head and present the changes of data into the position and movement in the virtual world (cf. Grimm et al., 2013; cf. Johansson, 2012).

At the moment, there are lots of products of HMD on the market with different functions and goals. The starting-level product, Google Cardboard, is an inexpensive HMD that can be built by the users themselves with their mobile phones and the basic working theory of HMDs. VR, with the cheap version of HMD, has been used in classes to demonstrate real-world phenomena and illustrate abstract concepts for the curricular for students in sixth and seventh grade in schools. The study shows that this kind of low fidelity of VR also gives students a vivid look at virtual places and virtual objects (cf. Vishwanath et al., 2017).

The first version of customer VR glasses, Oculus Rift CV1, triggered a lot of media coverage and the development of VR production in other companies and institutes, starting the era of modern VR HMDs. The product Oculus Rift CV1 has a resolution of 1080 × 1200 per eye, a 90 Hz refresh rate, a diagonal field of view of 110°, and a horizontal field of view of 90° with a continuous latency (cf. Gieselmann & Janssen, 2013). In the further generations of VR glasses (e.g., Oculus Rift S, HTC Vive Pro Eye, and PS VR), the screen resolution with stereoscopic function, the refresh rate, the transmitting rate, and other hardware data have been improved in various products. Taking Oculus Rift S as an example, it has a resolution of 1280 × 1440 per eye, a pixel density of approximately 600 ppi, and a refresh rate of 80 Hz with a 6-DOF inside-out tracking system.

Oculus Rift S (Oculus VR)[15]

HTC Vive Pro Eye (HTC)[16]

PS VR (Sony Interactive Entertainment)[17]

Figure 2-8 Examples of main VR Headsets

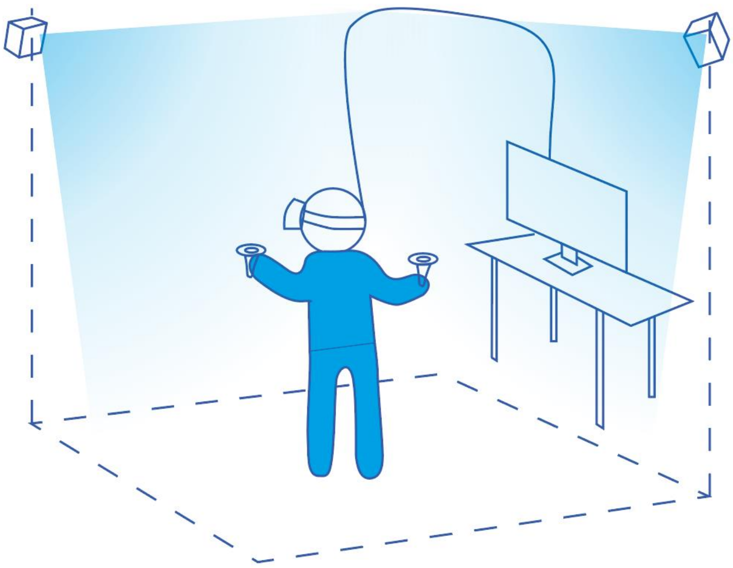


Figure 2-9 Illustration of the using area of the VR systems with a headset, controllers and base stations (source: own illustration)[18]

[15] Photograph of Oculus Rift S. (n.d.). https://www.oculus.com/rift-s/

[16] Photograph of HTC Vive Pro Eye. (n.d.). https://www.vive.com/eu/product/vive-pro-eye/overview/

[17] Photograph of PS VR. (n.d.). https://www.playstation.com/en-us/explore/playstation-vr/

[18] An illustration inspired by the user guide of the product HTC Vive: https://www.htc.com/managed-assets/shared/desktop/vive/Vive_PRE_User_Guide.pdf.

The comfortable visual distance between the users and the objects is a common condition that has a considerable impact on the user experience in VR. Anything too close to the eyes would cause pressure on eyes and minds. Anything too far from the users would be blurry, especially the objects with texts or pictures on them. For different hardware, suitable distances can vary based on the field of view and resolutions of the VR glasses.

The horizontal field of view of the human is approximately 180–200 degrees, with only approximately 30 degrees in the center with a highly detailed vision. Nowadays, VR technology offers mainly 360 degrees rather than a high field of view as a human, stitching the perceived panoramic view in the virtual world (cf. Richards, 2017). A study with the Gear VR explored the relationship between distance and stereoscopic feelings, finding that the further the objects are from the user, the less three-dimensional effect the user will feel (cf. Chu, 2014).

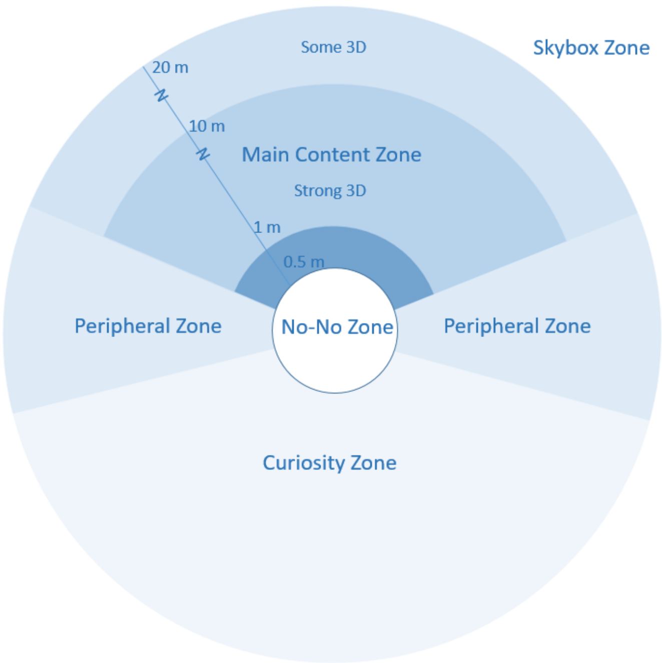


Figure 2-10 Design of field of view and depth in VR (cf. Alger, 2015; cf. Chu, 2014)[19]

In VR, the user has a comfort zone of field of view like in reality, which was studied by Chu (2014) with the products of Gear VR and Alger (2015) with the products of Oculus Rift, indicating a comfortable view range as in the following graphic. In the designing process of UI

[19] The exact angle and distance in the picture can vary on different hardware and software.

in VR, it is possible for the designer to make a UI as wide as 360 degrees, but the division is useful for the designers to decide where to put the important information and elements. The exact position range and angle range of the UX design in VR for the comfortable user experience can vary on various hardware.

The main content zone is where the user will focus on and interact. If the user wants to look at something in VR that is not in this zone, the user would turn the head or turn the body to look at it just like in reality, so the dynamic or static heads-up displays (HUDs) should always be in the main content zone. The peripheral zone has the function of reminding, attracting attention, and sometimes indicating that there are further options. Like in reality, if there is something blinking in the peripheral zone, the user would turn around to check it. The users in VR are not able to see what is happening behind them. For the elements in the curiosity zone, the users have to turn their bodies to satisfy their curiosity. If the body gesture of the user is relatively static because of the hardware limitations, the vision of users in VR is restricted without the curiosity zone. The no-no Zone is the place where no VR elements should be displayed to expect the elements from the users themselves, such as controllers and avatars. When the objects in VR get close to the eyes, the users would have uncomfortable eye strain or become crossed-eyes. The skybox zone is where the horizon of the scenarios is, such as the mountains and rivers or the street outside the windows without the requirement of interaction. From the technical aspect, the objects that are always in the skybox zone could be replaced by images to reduce the workload because objects far away from the users (e.g., over 20 meters) would look flat without 3D effects (cf. Chu, 2014).

In terms of the field of depth for the interaction, the distance, and angle that hands are able to move to affect the interaction in VR. If the headset and controllers have sensors for position tracking, the length of the arm is a reasonable distance between the user and the object in VR. The designer should take the arm length into consideration not only for the horizontal distance between the user and the object but also for the height of objects to reach. The user can raise his arm to touch an object that is higher than the headset or pick up a lower item by crouching on the ground. Additionally, if the user should work with their controllers in hands in the air for a long time, the VR elements should be lower down and close to where the arms already are. The less frequently used objects should be put far from the user so that the user would not touch them by accident. The more frequently used ones should be put nearer to the user for their convenience. In an immersive VR environment, the refreshed frequency of the digital monitor should be 90 frames per second for the user to have the illusion of being in the virtual space.

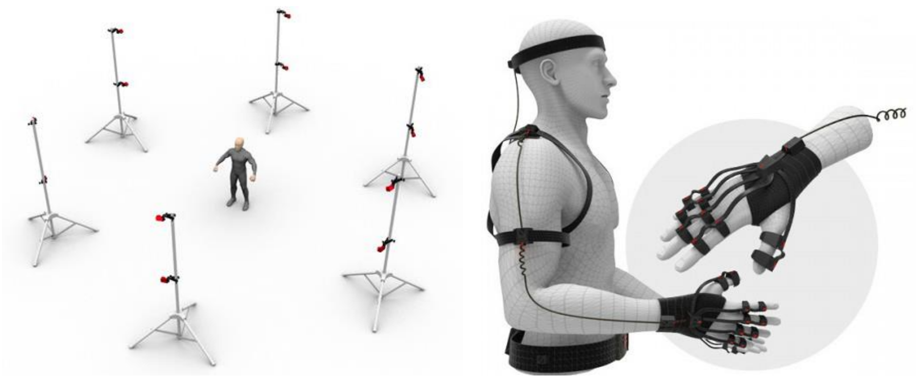
From the perspective of the technology of HMDs, tracking of the position and movement needs appropriate latency, update rate, resolution of the screen, as well as the field of vision for the transmitting of data and corresponding representation for the visual perception. A small discontinuity would be noticed by the user and may cause disbelief in the virtual environment and a negative physical impact on the well-being of users, like motion sickness. Additionally, the transfer of knowledge would be impacted due to eye and neck fatigue (cf. Cruz-Neira et al., 1993; cf. Johansson, 2012). Therefore, the potential confounding factors on learning experiences should be taken into consideration in the educational praxis. The CAVE equipment or dome theaters would have fewer limitations on the refreshed frequency, which is only 30 frames per second. The combinations with other technical research methods are also interesting to researchers. Eye-tracking technology can be embedded into HMD to record the eye movement trace, staring time, and even facial expressions in virtual learning environments (cf. Sharma et al., 2016).

2.3.2. Input for body movement and locomotion

The input of body gestures and locomotion, which is not as popular as the HMDs in the VR market, is an essential unit to complete the experience of a virtual reality environment or the feeling of immersion and presence experience. Additionally, the import of the body motion recognition and locomotion into the virtual environment can effectively reduce motion sickness and enhance immersion, especially with the interaction between the body and virtual scenes.

The motion capture based on inertial sensors requires the users to wear accelerometers, gyroscopes, magnetometers, and other inertial sensors to collect the data so that the motion can be calculated based on the principle of inertial navigation. The precise collection and calculation of the inertial sensors set could support the fine motion of finger moves as well as the movement of jumping and running, which would create the closest feeling to real-world interaction. Meanwhile, the equipment is complex to wear and not easy to be ignored with the data transmitting (e.g., Perception Neuron by Noitom). When it is only necessary to create part of the motion simulation in VR instead of the whole body, a VR chair with the sensor of rotation and position would be enough to deliver the simulation, such as driving in a tested car.

An optical body tracker system works with infrared LED array cameras and reflecting components are the main parts. The cameras receive the filtered infrared, which is emitted by the cameras and reflected by the marked reflecting points (trackers) in a passive optical tracking system (e.g., OptiTrack), and emitted by the trackers and directly received by the cameras in an active optical tracking system (e.g., Oculus Rift). The calculation of the signals from different cameras leads to the position of the marked point. The optical tracker system has very high precision, but with the problem of loss of sight when the infrared light is blocked in the room. The problem can be eased with more infrared array cameras, resulting in a higher cost for the system with many cameras set in the scenes, which is popularly used in the industry of animations and movies. The Oculus Rift has also infrared LED cameras to get the position of the headset and controller, with an internal sensor system in the headset to avoid the problem of infrared blocking.



OptiTrack[20] Perception Neuron[21]

Figure 2-11 Body tracker systems with optical sensors and motion capture sensors

Another optical positioning system is with visible light. The headset from PS VR with the blue lights and the controller with blue or pink lights would be an example of the applications. The cost of visible lighting position technology would be lower than the other optical positioning system, without complex algorithms afterward to calculate the position. However, the low precision of positioning and the relatively poor anti-interference performance would limit the application fields of this kind of technology.

The navigation in the virtual reality learning environment gives the learners the presence and

[20] Photograph of OptiTrack. (n.d.). https://optitrack.com/

[21] Photograph of Perception Neuron. (n.d.). https://neuronmocap.com/

immersive experience and enables the building of a larger space than the real available space for the interaction. From the perspective of hardware, the body movement and navigation in VR include the types of the “VR chair”, the locomotion treadmill, clothes with sensors, and other location and position technologies in space. From the perspective of the software and based on the features of hardware, the locomotion and body movement comes with the solutions of teleportation, moving-in-place, or just natural walking in the room with enough space. The input device, visualization systems, and movement strategies together build the navigation system in the virtual world. Sensors or cameras are inevitable as part of the input devices in VR (cf. Grimm et al., 2013; cf. Johansson, 2012). For example, the product of VIVE Tracker could be the solution of walking-in-place for navigation in VR environments, as well as the tracker as a body position sensor.

In some VR applications with no requirement for large virtual space, such as the simulation of only talking with others or chemical experiments at a desk, it is possible to utilize only the natural walking of the user, or just to walk without navigation. However, when a larger space is required as well as the navigation is needed, the solutions with sensors, programming, and movement strategies are meaningful.

An omnidirectional simulator ground allows free, physically real walking movements in all horizontal directions without physical barriers, offering a high degree of authenticity for training and learning scenarios where users have to be mobile or where it is about learning spatial structures (cf. Johansson, 2012). This type of navigation interface should be able to accelerate or break easily and instantly, guarantee the safety of the users without slipping or falling, and give physical feedback during the speed change (cf. Johansson, 2012). The products of omnidirectional walking still have a small part of the market due to their high cost and cumbersome size (cf. Schuster, 2015).

Solutions for an omnidirectional ground are firstly platforms with balls such as the “CyberCarpet” with the large steel frames and the combination of several treadmills (cf. Schwaiger et al., 2007, p. 415) or the “CirculaFloor” with a motion footpad for each foot (cf. Iwata et al., 2005). Examples of low-cost and convenient navigation interfaces come from the entertainment industry (e.g., Virtuix Omni and Cyberith Virtualizer), which stand out for their space-saving physical and technical characteristics. Taking Virtuix Omni as an example, it uses a walking platform to simulate the motion of walking, turning, running, and jumping. It mostly works with the Oculus Rift and other head-mounted displays and allows users to experience the natural moving in the virtual environment. With Virtuix Omni, users can freely turn toward any direction due to the careful design of the platform, which consists of a curved surface with many small circular recesses and smooth tracks on it (cf. Virtuix Technologies 2014). Users need to wear special shoes for moving on the Omni runway with trackers attached to them so that movements of feet can be tracked precisely. The bottom of the shoe has a recess-matching cone to stabilize the movement's pace and prevent positional displacement situations.

Virtuix Omni[22]

VIVE Tracker[23]

Figure 2-12 Examples of equipment for body motion and locomotion (source: own presentation)

In terms of the room-scaled VR technology, such as the applications with Oculus Rift and HTC Vive, the solutions of the navigation in the virtual reality environment would be different from the ones with omnidirectional treadmills. The room-scale VR headset has the possibility of real walking in a restricted space, while the other methods are necessary for the user to move further from the standing point in VR. The positioning functions of the base stations of the room-scale VR systems are laser-based positioning technology, a relatively inexpensive realization of positioning in virtual reality. For example, a set of HTC Vive systems has two Lighthouses to emit lasers. The trackers (on a headset, controllers, or VIVE trackers) operate on an inside-out principle and receive the laser with many photosensors, calculate the angle and distance

[22] Own photograph. More Information about Virtuix Omni: https://www.virtuix.com/

[23] Own photograph of VIVE Tracker. More detailed information: https://www.vive.com/de/accessory/vive-tracker/

differences between various photosensors mathematically, so as to get the precise positions and rotations of the trackers (cf. Niehorster et al., 2017). Additionally, in our laboratory, it has been proved that two sets of HTC Vive with six tracking devices can work together fluently with no performance problems or light-blocking problems.

Teleportation in VR may be the most used moving method in a large virtual space. It is usually triggered by pointing to the destination and interacting with one button on the controller or gazing at the destination for several seconds. Real walking inside a restricted space (e.g., a square with a side length of five meters) is possible with the hardware of a room-scale VR system. It gives the user the most realistic moving experience in VR with physically walking. Taking HTC Vive as an example, the interaction layers is divided into three regions, the whole VR scenario as the teleportation area, the walking area, and the arm-reachable area, as displayed in the graphic below.

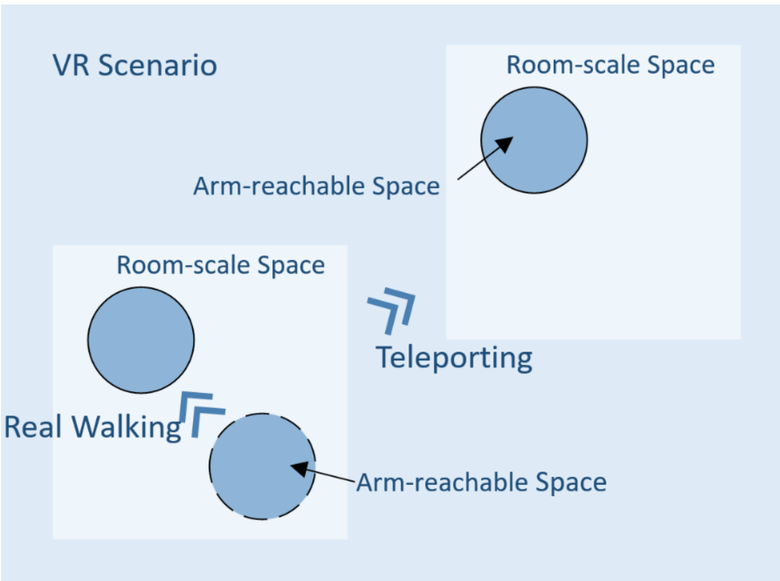


Figure 2-13 Division of interaction regions with room-scale VR (source: own presentation)

The method of moving in-place, in many cases, is suitable when it is necessary for users to walk in a relatively short distance (e.g., 5-20 meters), because it needs more physical strength of users and may lead to exhaustion (cf. Zinn, Pletz, Wadas, & Guo, 2020). In the case of moving in-place, the body movements, such as stepping in-place, should be tracked with sensors attached to the legs or feet. A simple hardware example would be the VIVE Tracker, which could be attached to the body shown in Figure 2-12. There are also methods of redirected walking and navigation with joysticks, which are not often used as the others in the VR field because of the ergonomic limitations.

2.3.3. Input for hand gestures and output for haptic feedback

In the context of teaching and learning in a virtual reality environment, input and output devices of a real hand gesture may enable learners to interact directly with objects rather than to imagine the real movement, which has great value in different learning scenarios with various interactions and movement of students. The method of interaction with the interface and the method of interaction with the content are coinciding, leading to the presence experience of "being in the world" and "acting in the world" (cf. Fontaine, 2002; cf. Steuer, 1992). For example, the user can click the mouse to interact with a door with a desktop computer. In VR, the user would directly reach out to the arm, grab the doorknob, turn it and open the door.

Sagayam and Hemanth (2017) surveyed the technology of hand posture and gesture recognition for virtual reality applications, indicating the characteristics of various kinds of techniques as well as the significant contribution of human gesture recognition for HCI. Direct manipulation is a key concept of the designing and development of interaction with a high-end immersive VR setup (cf. Dörner et al., 2013). Interactive buttons are necessary for the selection. It means that if the user puts their hand (Controller) on it or points at it with a light pointer, the buttons should be responding with hovering, highlighting, size-changing, or shape-changing.

Input devices for hand movements transmit information data of human movement to the processor of a computer, and the data is collected by sensors of the devices, which have to be able to react sensitively in order to simulate as naturally as possible. Only if the interaction between the real body and the virtual objects is responsive and accurate, the users can have an immersive experience in the interaction. The output devices of hand movement include normally visual feedback and haptic feedback. Feedback of the visualization system through desktop monitor or HMD shows the real-time hand movement in a virtual reality environment. Through vibration, motion, or force, haptic feedback offers an opportunity to involve the sense of touch of a user into the simulated environment (cf. Grimm et al., 2013; cf. Johansson, 2012). Normally the input process and output process of hand movement data are combined into one device, as in some of the following examples.

Vibrotactile devices support the user to perceive objects in a virtual environment through vibration. Normal virtual reality data gloves only have input functions. The representative device is the data gloves from the company 5DT[24], which has the realistic real-time animation of hand movement with 5 or 14 sensors per glove, high data quality, and low cross-correlation of data. Another form of data gloves has the function of both input and output. The force feedback from data gloves offers users the feeling of actually holding something or pushing something when they do the same movement in a virtual environment. The representative product is the force feedback data glove from the company "CyberGlove"[25], which has also developed the product "CyberForce" with the added force feedback of a whole-arm in order to realize the complete immersion in virtual reality. The product of CaptoGlove shows the possibility of the technology of data glove for the normal customer for a wide application in the gaming areas and other applications. With a simple driver, the product could be easily applied to PCs and VR HMDs. Additionally, the new technology of Magnetorheological fluid (MRF), which can change the liquid level proportional to an applied magnetic field, represents a further possibility for haptic feedback gloves (cf. Najmaei et al., 2015).

5DT Data Glove[26] CyberForce[27] CaptoGlove[28]

Figure 2-14 Examples of data gloves

In some circumstances, when the freedom of hand moving is more useful and the haptic feedback is not so necessary, visual feedback from the device will be enough, especially for the students learning in the virtual environment. A representative device would be Leap Motion[29]

[24] More information about the technology: https://5dt.com/

[25] More information about the technology: http://www.cyberglovesystems.com/

[26] Photograph of 5DT Data Glove. (n.d.). https://5dt.com/

[27] Photograph of CyberForce. (n.d.). http://www.cyberglovesystems.com/cyberforce

[28] Own photograph of CaptoGlove. https://www.captoglove.com/

[29] More information about the technology: https://www.ultraleap.com/product/leap-motion-controller/

Controller, with the technology of computer vision-based motion capture. It can sense the different movements of fingers and palms, translate the moves into data, and show the corresponding move of the hand models in the display devices, no matter desktop monitor or HMD Oculus Rift. Based on the technology of infrared LED and grayscale camera, it collects the movement and shape data with the XY field of view of 150 degrees and the YZ field of view of 120 degrees and builds 3D data with a complex algorithm (cf. Curiel-Razo et al., 2016).

With the assistance of the infrared channel and the upcoming Dragonfly module of Leap Motion, it plays a crucial role in the next generation of 3D interactive systems. The hands-free character of this tracking technology is one of the attractive points of the products, which provides a closer-to-real interaction feeling, but the low anti-interference performance and high requirement for calculating and processing would be obstacles to precise recognition.

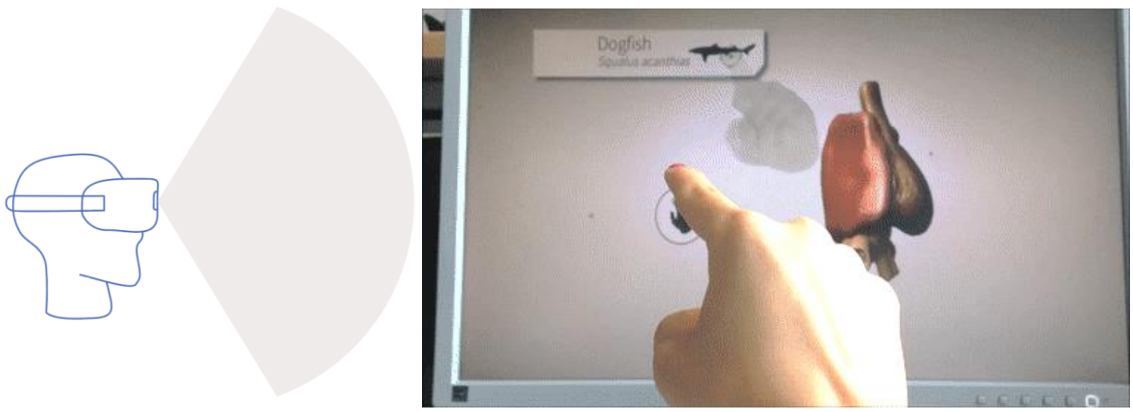


Figure 2-15 Applications of Leap Motion with a VR-headset and a desktop computer (source: own presentation)

Additionally, there are still other fields to be developed in terms of input solutions, such as the products in the field of augmented reality. An example would be the Hololens-compatible MRTouch developed by a team at Microsoft and presented at the IEEE Conference on Virtual Reality and 3D User Interfaces, which may offer precise as well as comfortable user input (cf. Xiao et al., 2018). Another example would be the augmented reality glasses Hololens and Google Glasses, which are also important products in the edge technology for input and output (cf. Peddie, 2017).

This section focuses on the technical aspects of a virtual reality learning environment, including the input and output for head movement, body movement, and hands gestures. Various technologies provide different functions and have their own advantages and disadvantages. The VR headset was firstly invented for an immersive experience, and the CAVE is also for virtual presentations on a larger scale. For a more accessible variety of the VR headset, the Cardboard gives the users a basic demonstration of the VR environment with integrated mobile phones. In contrast to the cheap Cardboard, the immersive room-scale VR headset brings the user a more immersive and interactive world. In order to offer an authentic environment, the synchronization and the simulation of the body movement and the hands' movement are necessary to develop and apply along with the environment, including the hardware of optic sensors, omnidirectional running simulator, data gloves, as well as the software implementation of teleportation, optic analysis, and the synchronization.

2.4. Considerations of the application of VR

As new technology in the field of learning is introduced, both the industry and the pedagogic professionals are trying positively to take advantage of the new items. From the aspect of hardware, the technology of hardware has greatly improved in the past years since the boom in the area of virtual reality in 2016. However, the technological limitations of VR still exist and should be taken into consideration.

2.4.1. Simulation technology

Although the presence experience in virtual reality is relatively high in virtual reality, the simulation with the technology of virtual reality is still not ready to deliver a totally realistic environment for training and learning, which is the same as the real environment.

The resolution is not enough for users to experience real life. For example, the HTC Vive Pro has a resolution of 1440 x 1660 with a max screen refresh rate of 90 Hz and 110 degrees of field of view. One of the widest VR headsets is PIMAX 8K PLUS[30], which has a resolution of 3840 x 2160, a field of view of 200 degrees, and a screen refresh rate of 120 Hz.

The cause of the simulation problem is mainly the latency problem. For example, the refresh frame rate for the immersive VR glasses Oculus Rift is 90 Hz, refreshing 90 times every second and about 11.1 ms every time. Then, if the refreshing time for every frame is close to 11.1 ms, the frame rate for the whole application would be steady and close to 90 Hz. Otherwise, if the

[30] Information about PIMAX: https://www.pimax.com/, retrieved date: Feb. 23th, 2020.

frame building time is more than 11.1 ms, the graphics will not follow the refreshing, and the latency will appear. Measures could be taken to hit frame rate, such as limiting the number of draw calls, the number of textures, and the time spent in scripts[31]. However, for every kind of application with virtual reality, if it is hitting the frame rate, there is no need for further optimization of the application when it has no impact on the user experience.

2.4.2. Ethical aspects

The technology of VR, in line with other technologies, has its general risks in the application. The exposure to sensible content and the exposure of vulnerable people should be taken into consideration. For example, children or adolescents may not distinguish the characteristics in VR and in the real world, and certain psychological patient groups may be very vulnerable to the content and environments in VR (cf. Slater et al., 2020).

Physical protection, based on the application scenarios and the related VR equipment, should be required. For example, protection settings with people or safety facilities should be required, especially with an immersive walkable VR scenario. The immersion and presence experience would lead to the misrecognition of real and virtual environments and objects. Although it brings beneficial effects on the learning processes, it has, to some point, risky potential in safety with the hardware and software, which should be taken into consideration in the design, development, and implementation. Taking the virtual navigating signs and arrows in the AR-mode of the application Google Map[32] as an example, they are active when the users are standing still and deactivated when the users are walking with the mobile phone, avoiding the potential traffic risks. In addition to that, without outer protection, the individuals immersed in the virtual reality are exposed to the outside spaces and individuals. It is important to ensure that the users of the VR applications are safe, and the learners in the VR scenarios could focus on the learning processes.

From the perspective of ergonomics, the feeling of motion sickness (also known as simulation sickness, cyber motion sickness) is one of the most discussed negative issues when it concerns

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[31] More information about the measures on frame rate: https://developer.oculus.com/documentation/native/pc/dg-performance-guidelines/ retrieved date: Feb. 25th, 2020

[32] More details about the AR mode of the application Google Map: https://www.google.com/maps.

the usability of a virtual reality environment, usually including the symptoms of dizziness and nausea. It is a mismatch between what is seen in the virtual world and what the body feels about the physical movement caused by latency or balance and navigational problems. Studies examined the technical and medical reasons that cause the sickness, which is mainly the difference between the distance of position movements in VR and the distance the brain expects, including uneven acceleration (cf. Dörner et al., 2013; cf. Munafo et al., 2017). The syndrome, such as sickness, fatigue, and dizziness, is also one of the obstacles for users to experience virtual reality for a relatively long period. Studies show that if the display were not attached to the head directly like HMD, but in a CAVE, for example, the disorientation, discomfort, and motion sickness would be less (cf. Cruz-Neira et al., 1993). In VR, the camera is mapped to the eyes of users. Changing or moving the environment against the users is forbidden, which will lead to motion sickness. In addition to motion sickness, the virtual reality environment can cause eye strain, disorientation, and other unpleasant feelings as well. To avoid such negative effects, some trade-offs have to be made, such as increasing the quality of the images, increasing the frame rate of images (e.g., minimum 60 frames per second with the hardware Gear VR is suggested), avoiding fast-moving and acceleration of users, decreasing the display lags and maintaining perceived and rendered depth in the virtual reality environment (cf. Chu, 2014).

The impact on the psychological well-being of users is also a risk of VR technology, such as the risk of trauma, after being in a disrespectful virtual environment or the social isolation in the real world after spending much time in VR. Some of the after-effects may be temporary, while others could be long-lasting (cf. Slater et al., 2020).

Just like other technologies, the ongoing discussion about data-related issues (e.g., user privacy) is also in the VR application fields. Generally, with innovative technology, more interaction and more personal data are collected than with traditional technologies, in order to fulfill precise and intelligent feedback or research goal, such as interaction, movement of eyes, bodies, hands, and heads, as well as the analyzed results through the collected data. Although there will be some time before the standards of the design and development of the applications of VR in the field of data-related issues are developed, the significance of the issues should not be ignored.

The risks brought by the immoderate use of VR and the content and technology of VR itself are different. The moderate and appropriate use of VR could be beneficial to the users. There is no norm to define the use frequency or the use time length of the VR products. However, there are regulations to the design and development trying to minimize the harm to the users, such as warning of the safety risks and additive risks before the user enters the VR world and the manual for the users to protect themselves (cf. Slater et al., 2020).

This section indicates that the limitation of the technology of VR is what should be taken into consideration before the design, development, and implementation of the technology. The simulation technology is one of the major features of VR; however, the resolution, the display size, the frame rate, and other coefficients are still not advanced enough. From the perspective of implementation, the ethical aspects are not to be ignored. Such as the issues of exposure to vulnerable individuals, physical protection, motion sickness, and data-related issues.

2.5. Interim conclusion to virtual reality technology for learning

This chapter introduces the technology of virtual reality for training and learning from the perspective of history, the features, the concrete techniques, as well as the limitations of the technology of VR.

Because of the drop in the cost of technology in the last few years, immersive VR is applied in many fields. However, it is not so long since the technology became popular in the market. Therefore, there are all kinds of hardware and software with different designs, and there is no standardization of the application of the technology, especially for the user interfaces, which could be seen in Section 2.2.

In the virtual reality environment, both hardware and software can influence the level of immersion, the feeling of spatial presence, as well as other perceptions of the user experience, which, in the context of the training and learning, could affect the learning effects and outcomes. Therefore, the various features, technical aspects, and limitations of VR technology should be studied carefully and thoroughly in order to make the right decision in the design, development, and implementation of a virtual reality learning application. For example, for most of the vocational schools, the expenses and barriers to access to VR, from the perspective of hardware, equipment, and personnel, remain significant in practice, which will be discussed in Study II.

Therefore, it is meaningful in this research to study the history, the various features, the technical aspects, and the limitations of the technology VR firstly before the design, development, and implementation of the virtual reality learning sessions of VILA (Chapter 6) and VPSL (Chapter 7).

3. User Experience in Virtual Reality[33]

In the ISO 9241-210 (cf. International Organization for Standardization, 2019), the user experience is defined as "user's perceptions and responses that result from the use and/or anticipated use of a system, product, or service." "Perception and responses" include "emotions, beliefs, preferences, perceptions, comfort, behavior and accomplishments that occur before, during, and after use". Hartson and Pyla (2019) defined user experience as "the totality of the effects felt by the user before, during, and after interaction with a product or system in an ecology". User experience is "a result of indirect or direct interaction". It is "about the totality of the effects", including the influence during physical interaction and the full unfolding of effects over time. User experience is felt internally by the users, and each context affects the user experience (cf. Hartson & Pyla, 2019). The center of the product design should be the user experience from all the perspectives that the users see, hear, feel, and other experiences, instead of pure content conveying, storytelling, or technology utilizing.

In the context of training and learning, the user experience of the learners would be the learners' total perception of beliefs, emotions, comfort, accomplishment, and other perceptions before, during, and after use of the learning product or learning system. The subjective learning experience felt by the learners is the consequence of the images, presentations, the interactions of the system together with the learning experience, motivation, ability, and other internal or external learning states of the learners.

In this chapter, the related concepts and elements concerning user experience will be discussed, including usability, user interfaces as well as the constructs of the user experience, especially focused on the learning applications with the technology of virtual reality.

3.1. Usability

Originally, the term usability can be applied to the subject that has interactions with humans, a tool, a book, a website, a machine, software, or other interactive objects, applying the ease to use, learnability, and user-friendly features. The analysis of usability may be helpful to the design of machines, the development of websites, or the updates of software. In terms of

[33] A part of this chapter was published in the article of Guo (2020).

interactive IT products or systems, usability is one of the most important indices, indicating the quality of interfaces from the view of the users and customers, which is the core competitiveness force of products or systems. Since the interactive computer learning software came into practice, usability has frequently been an important topic in learning interfaces (cf. Bolas, 1994).

Usability is defined by the International Organization for Standardization (1998) as “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use” (cf. International Organization for Standardization, 1998). Effectiveness is “accuracy and completeness with which users achieve specified goals”, efficiency is “resources expended in relation to the accuracy and completeness with which users achieve goals”, and satisfaction is “freedom from discomfort, and positive attitudes towards the use of the product” (cf. International Organization for Standardization, 1998).

For the design of user interfaces in the area of information technology, the International Organization for Standardization (2006) gives seven dialogue principles, including task appropriateness, self-description, controllability, conformity to expectations, error tolerance, customizability, and suitability for learning. Other researchers also proposed other frameworks for the criteria of usability, and some principles were highlighted, such as the principle of visibility of system status, which states that users should always be informed of the status of the application with appropriate feedback, and the principle of recognition, that users would be able to see the visualized information and their dialogues instead of remembering the information and recalling it when they need (cf. Nielsen, 1994).

These principles do not concern only the interface design, but the system and process design as well. Also, principles of usability in different situations have different meanings, such as professional users versus new users, immersive environments versus desktop environments, and various applied businesses.

Virtual reality systems may suffer from severe usability problems like conceptual disorientation or inability to manipulate objects, leading to a need for usability evaluation of virtual reality platforms and a better immersive virtual display application (cf. Bolas, 1994; cf. Sutcliffe & Kaur, 2000). As a non-functional attribute, usability cannot be directly measured. Instead, it can be measured by means of indirect indices like the objective error reports or the subjective evaluation of users. Although the knowledge of HCI (Human-Computer-Interactions) helps the accuracy of evaluations, they can be carried out by individuals with no HCI training.

Based on the interaction model of Norman (1986), which is the foundation of the cognitive walkthrough method (cf. Wharton et al., 1994), Sutcliffe and Kaur (2000) developed an extended walkthrough approach to describe users' mental and physical actions in 3D worlds, facing the new problems posed by VR and specific designs, such as navigation, orientation, and movement. The walkthrough procedures are divided into the main task-action cycle and two sub-cycles, navigation, and system initiative (cf. Sutcliffe & Kaur, 2000).

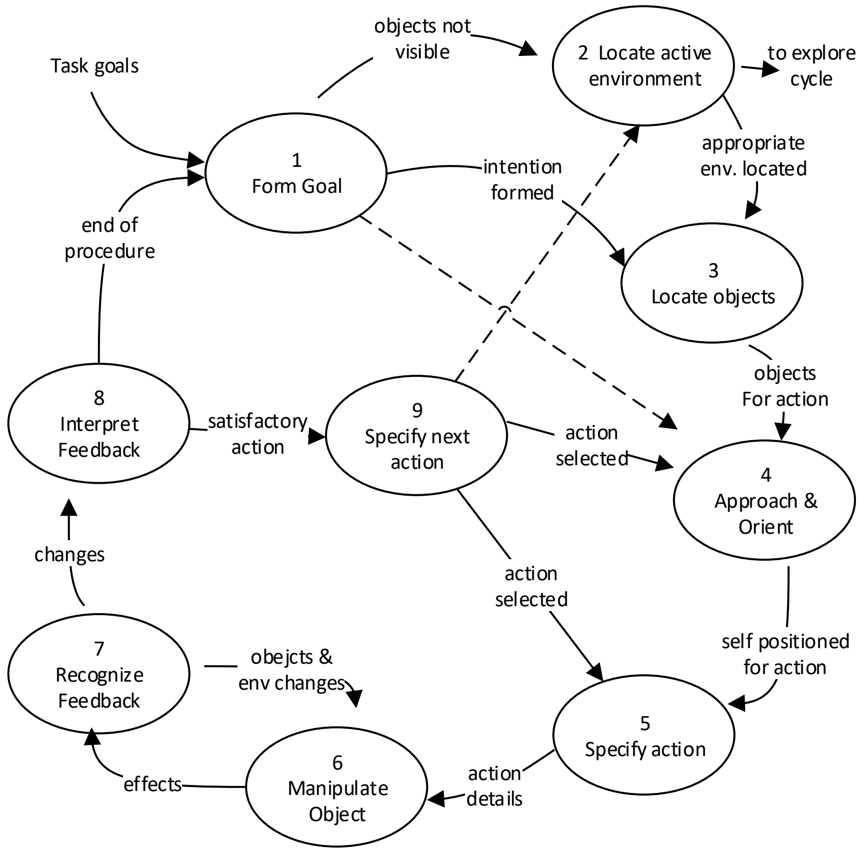

Figure 3-1 A VR interaction model of cognitive actions (Sutcliffe & Kaur, 2000)

In terms of the virtual reality learning environment, the developing process may take advantage of principles of usability engineering to build a more effective, more efficient, and more satisfying virtual learning environment. Sometimes complex tasks may lead to difficult environments, which alternatively promote active learning (cf. Sutcliffe & Kaur, 2000). Thus, a balance point between constraints on natural interfaces and usability is necessary for a better virtual reality environment.

3.2. User interfaces and user interface designs

In the field of Human-Computer-Interaction (HCI), the definition of a user interface and its features have radically changed. The term of a user interface (UI) comes firstly from the interface of personal computers, especially the command mode of the monitor under the paradigm of WIMP (windows, icons, menus, and pointer) (cf. Beaudouin-Lafon, 2000). The researchers started to pay attention to the effects of user interface on the user experience of the operation of computers in the 1990s when the operating system of computers evolved into a fully functional system. After that, many paradigms of UI were established. In 2000, HCI (human-computer-interaction) became a subject in the field of computer science, whose researching results improve the following development of computer applications (ibid.).

In the concept, design, and development phases of computer applications, contemporary UI plays a vital role in guiding the user flow, providing instant feedback, promoting user motivation, and even influencing the user emotions. This is exemplified in work undertaken by Agarwal and Meyer (2009) on emotional responses as an integral part of user experience, indicating significant differences between the emotional responses of users using two kinds of user interfaces in the learning application.

The recent development of VR brings the reconsideration and redefinition of UI based on the new hardware technology usage and application scenarios, which will be talked about in this paper. The presentation of the user interface of VR relies mostly on the possibilities of hardware. For example, users with the VR application based on simple mobile phone operate selection and interactions with the sight fixation point and head rotation, whereas a user with room-scale VR achieves the selection and interaction with the matched controllers, which is closer to reality with arm movement (cf. Yoo & Parker, 2015).

With the development of information technology, the user interface (UI) occurs in order to let humans control the machine from the perspective of a human, where the interaction between machine and human happens. When a man clicks on the mouse or taps on the keyboard, it is an action of the input and gives a command to the computer. After the processing, the computer shows the feedback on the display area of output devices like the monitor. In this situation, the user interface includes the mouse, the keyboard, and the monitor, as well as the displayed visual system through which man can input and get the output. The user interface is the bridge that connects humans and machines, which refers to the related hardware, operation systems, software, and even the pictures on the website that show where to click.

With ubiquitous personal computers and access to the internet, the term “user interface” generally refers to the graphical user interface of operating systems of computers. Therefore, the user interface design is gradually becoming one of the focuses of software designs, whose goal is to offer better usability for users to control the machine and achieve the desired result.

The user interfaces with human-machine interfaces with human-computer interactions have greatly improved from the beginning of appearing. The user interfaces of mobile phones have also gradually developed from button interfaces to today’s natural moving patterns.

In the batch-based interface era, the rudimentary interface with punched holes and buttons, and without monitors, gives no instant feedback to users. The appearance of an explicitly designed user interface comes with the representation of monitors. The command-line interfaces (CLI) with text command inputs and outputs through keyboard and monitor brings more possibilities of human-computer interactions, which is now still in use in the operating systems. A certain syntax is necessary to call the function in the operating system, which is still in the modern operating system (e.g., Microsoft Windows) working for operating system developers and maintainers (cf. Stephenson, 1999).

Envisioning a display system, where users could receive information graphically and jump to whatever interested them, Engelbart (1962) published his ideas on the graphical user interface with an example of an architecture designing program. The graphical user interface (GUI) is still one of the most frequently used interfaces in daily life and working with computers. It accepts input via devices like a keyboard, a mouse, or a drawing tablet and outputs on the visualized monitor with the desktop metaphor, WIMP (windows, icons, menus, and pointers), buttons, toolbars, dialog boxes as well as other simulations. Moving the mouse and clicking on the icons are more effortful than the conduction of command lines (cf. Hartson & Pyla, 2019).

The new developing technology has shown the direction of the interface development, the natural user interface (NUI) with intuitive controlling processes with natural moving patterns. Compared to the former interface GUI, from the technical perspective, NUI is more complex in development and design, but it is simpler and more direct from the users’ perspective, with all the technical procedures capsuled in background systems and only the natural interactions are shown in the front end. One of NUI features is post-WIMP, such as simultaneous speech and hand input, which is optimal for complex tasks that require instant 3D interactions and reality-based interactions (cf. Bollhoefer et al., 2009).

The goal of the interaction between human and machine in the NUI is to make the user act and feel natural by creating the experiences that the users could feel like an extension of their bodies and as natural to a novice as they do to an expert with the right metaphors, visual indications, feedback and input/output methods for the context (cf. Wigdor & Wixon, 2011).

Surface-Hub[34]

interactive multi-touch coffee table with tangible support[35]

Communication for sign language users[36]

Figure 3-2 Examples of natural user interfaces and tangible user interfaces

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[34] Detailed information online: https://www.microsoft.com/microsoft-surface-hub/de-de

[35] Detailed information online:http://ideum.com/creative-services/interactive-coffee-traceability-prototype-experience/

[36] Detailed information online: http://research.microsoft.com/apps/catalog/default.aspx?t=projects

The most used NUI interaction models are two-dimensional and flat, like a touch screen with GUI (e.g., iPad). A multiple touch screen makes it easy for people to control the equipment by swiping or tapping to activate a function, zooming in a picture, or scrolling a long article without a button to click. Other NUI examples include using gestures and voices to interact with computers and mobile phones. With the gesture interactive device (e.g., Infrared Projectors of Kinect), the system can capture the gestures of humans, recognize their meaning, and translate the sign language into any natural language, which helps people who have problems with hearing and communicating. The interactive voice systems (e.g., Cortana or Siri) conduct commands and return individualized feedback based only on the voice queries of the users.

There are also other less-used interfaces, such as the eye-tracking interfaces and the brain-computer interfaces, which are often directed to the researching fields. TUI (tangible user interface) is a user interface with which the user transmits digital information through the physical movement and the physical manipulation of the objects in the real world, offering instant feedback through the interface. The application of a TUI offers an embodied experience with physical interaction. A common implementation of a TUI would be a table with a touch screen and sensors to get the position or rotation of the interactable objects with a marker on the table.

Besides the traditional classification of user interfaces, there are some other kinds of user interface classifications and types. Based on the difference between human-machine-interactions, there are direct user interfaces and indirect user interfaces; based on the difference of connections and collaborations, there are web user interfaces (WUI) and local user interfaces; based on the difference of interactive form, there are text user interfaces, voice user interfaces, and gesture user interfaces.

The UI in a 3D environment is different from the way it is in the 2D desktop interface. Most of the behavioral principles are still applicable, but there are more options to realize an interaction in VR. The methods of interaction with objects are different concerning different hardware. The VR glasses with controllers have the possibility of direct interaction, while the interaction realization of a barebones VR setup is relatively limited. In an immersive virtual reality, no matter if it is with high-end technology like Vive or a simple setting like Cardboard, the movements of the head and the field of view of a full three-dimensional vision are possible, leading to an immersive environment with sound, light, and shadows of the objects in the virtual reality. With the barebones setup (e.g., Cardboard), the users can only use the gaze time, gaze point, verbal commands, or head rotation to realize the possible interactions. When gazing is used for interaction, the gestures of interaction should be distinguished from the gestures of simple looking. Otherwise, it could lead to operation errors.

Heads-up displays (HUDs) are the screens that always display in front of the visions of the users, such as in the left-down corner or center of the screen. It is popular with the flat displays of PCs and mobile phones to present a real-time change of scores, time, and other instant messages. However, it should be adapted to virtual reality applications. For example, the vision of the message for the users with the virtual reality glasses should be in the center area of the field of view if it is necessary for the user to turn their heads, or there is a resetting system that could reset the position of the HUD. From the kinetic habitat and the pre-setting of the most virtual reality equipment, users are used to turning their heads to make the target in the center. Still, HUDs are practical as a temporal out-of-game menu, such as the settings of volume or the setting of the brightness of the screen.

There are two methods to realize the in-game menu in addition to the out-of-game menu with HUDs, static menu and dynamic menu. Static menus are the canvas of the menu that is set on a wall, a plaque, a table, or other flat spaces, like a static panel of a machine in reality. The user moves to the panel and actives the buttons on the menu with controllers or hand movements. Dynamic menus are the moveable panels in hand or moving along with users in VR. The depth of view is an issue to take into consideration in the dynamic menu. If a user calls up a menu, the designer should consider whether the menu is blocking other objects or whether the menu is blocked by other objects in VR. Using different kinds of menus or optimizing the canvas size to adapt to the scenarios' space size or distance could, to some extent, ease the problem.

What is meaningful to mention is, that the technologies of the other UI (e.g., text UI) forms could still be applied in the 3D environment with the corresponding adoption, such as the new text rendering pipeline (e.g., Text Mesh Pro[37]) for the VR environments based on the former UI-text rendering technology, providing a more realistic and clear view of the text in the learning and training virtual environments.

[37] Text Mesh Pro is a text solution for the development platform of Unity and provides better performance than the former text UI technology (Text Mesh Pro: https://docs.unity3d.com/Manual/com.unity.textmeshpro.html).

User interface design is now a critical position in the development of applications; behind the user interface design is the concept of services for users, with the help of input and output tools as well as software applications. Therefore, the topics of ergonomics and usability are critical for designers to take into consideration (Bollhoefer 2009, p. 5). According to Groner et al. (2008), in the analysis of the requirements of a natural user interface, user interface designers should pay attention to three points: for which target group it is developed (experience, competence, and settings), in which application context it will be applied (tasks, goals, and expectations), and in what kind of conditions it is implemented (social environment, technical environment and willingness to pay) (cf. Groner et al., 2008, p. 431).

3.3. User Experience in VR and its constructs

User experience (UX) has been disseminated widely in the Human-Computer Interaction (HCI) community. In the context of HCI, UX, defined as a "person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service" (cf. International Organization for Standardization, 2019), describes the inherently personal emotional and evaluative state of a user, before, during or after the interaction with the products, system or service. Based on the definition by ISO, a research group surveyed 275 researchers and practitioners for the understanding, scoping, and defining of UX, indicating that UX is dynamic, context-dependent, and subjective (cf. Law et al., 2009).

UX is an interdisciplinary area that integrates different perspectives and requires a holistic analysis. A special interest group workshop at the conference CHI 2011 discussed the theoretical roots of UX research (cf. Obrist et al., 2011). The qualitative analysis result shows the seven categories with a link to UX research and practice, including human/user, product/artifact, user/artifact/environment relations, social nature of UX, design, frameworks with several themes, and broader frameworks related to human existence, addressing the need for more attention on UX theories (cf. Obrist, Roto, Law et al., 2012). Experience has been studied by different disciplines, among which psychology dominates. However, other disciplines like sociology, pedagogy, and philosophy have the potential to provide a broader view of UX, such as the perspective of human values and sustainable aspects beyond interaction designs (cf. Obrist, Roto, Vermeeren et al., 2012).

Nowadays, most of the functional areas of UX, including the applications on the mobile phone, websites, and computers, have matured and completed the UX design system after development and improvement for many years. However, because of the relatively small number of users, the technical difficulties of development, the rapid update of the technology, as well as the variety of technological systems, there are only a few studies about UX in immersive virtual reality. Although UX includes the whole user interface system, interaction of software and hardware, it is not only the extension of technology and content but also the preference and the attention of users in all the processes of survey, design, development, application, evaluation, promotion and other steps for the products. It is, therefore, necessary for researchers to have a deep understanding of the design as well as the evaluation of UX in VR.

3.3.1. Immersion

As for the characteristics of the virtual reality user experience, the first thought would be immersion. Heretofore, the explicit definition of immersion has not been raised by scholars because of its complexity and multiple perspectives, including a broad spectrum of phonemes in various forms and leading to different results (cf. Schuster, 2015). Fowler (2015) proposed a framework with the conceptual tools to support the design of learning systems from both the pedagogical and technological perspectives, indicating that immersion offers a concept that bridges the technological, psychological and pedagogical, experiences in a VR environment.

Immersion is used to refer to the physical experience of being submerged in water, but now immersion refers to more of a sensation of being in a completely different environment that takes over attention and perceptions (cf. Murray, 1999, p. 98). The term immersion is frequently used as a subjective impression that one is participating in a comprehensive, realistic experience, which includes suspension of disbelief, cognitive involvement, spatial presence, and other symbolic factors that lead to this digital experience (cf. Dede, 2009). To create sensory immersion, total sensory interfaces are utilized, such as head-mounted displays, stereoscopic sound, binaural audio, vibrations, and motions. The sound design could improve the immersion and presence experience of users by mimicking a virtual 360-degree sound environment. For example, the voice of an avatar could be perceived by the users from the virtual position where the avatar is. In addition to the immersive effect, sound positioning is also helpful in the scenario where multi-users should speak to each other.

It is also argued that the main character of immersion is the distraction and diversion from normal time and normal locations. So far, an explicit definition of immersion has not been raised by scholars because of its complexity and multiple perspectives, including a broad spectrum of phenomena in various forms and different results. Immersion in virtual reality has at least the following characteristics: teleporting of time and space, interaction with the machine, and autonomic activities (cf. Hoffmann et al., 2016).

The immersive situation could occur in many cases. From a historical and cultural perspective, the application of immersion has been in human history for a long while. The idea of transporting people virtually to another enclosed illusionary environment with different sensations has existed since ancient times, and the methods of realization of this kind of sensation have been developed since then, such as an area of ritual action or a public sphere of politically suggestive power (cf. Grau, 1999). When the audience finds itself amidst the life-sized, highly realistic, and scenographic frescoes of the second Pompeian style, the 2D-view is transferred to 3D-view, and the borders between physical reality and virtual reality seem to dissolve (cf. Grau, 2002). Because of the enhancement of vividness and the new perspectives of interaction in virtual reality with the life-sized scenes, the user interface presents the user with stronger feelings of immersion than the traditional learning method in some scientific visualization tasks (cf. van Dam et al., 2000).

One of the most remarkable 360-degree immersive spaces in the Renaissance would be the Sala delle Prospettive by Baldassare Peruzzi, surrounding the audience with a virtual columned hall and illusionistic views of the countryside (cf. Ewering, 1993, p. 57). After the Industrial Revolution, the imaging and recording technologies provided the audience thitherto unknown dimensions of illusionary effect. The photographic technology panorama gives onlookers an illusive sensation through time and space. Most of the developments of immersion apparatus were firstly in military invention and later become popular in public, such as panorama in the early nineteenth century for political propaganda (cf. Grau, 1999, p. 369). Technologically, the immersive sensation of virtual reality has nowadays developed through the time of stereoscope, cinema, stereopticon, photorama, sensorama, and IMAX-cinema, to a real-time and constant computing era with increased processor capacity.

Immersion is not all or nothing, but rather a multidimensional continuum (cf. Bowman & McMahan, 2007). The immersive levels of various technologies are explained in Chapter 2.

From the aspect of immersion, not only do visual stimulus and experience have effects on immersion feelings, but also the sensations of auditory (background noise and music), olfaction, tactility (data gloves), and movement. The technical part of media elements plays an important role in user experience in VR. Bowman and McMahan (2007) indicate that the components of immersion are limited to the rendering software and input software (Figure 3-3). All kinds of equipment for virtual reality make the immersive sensation easier to realize, such as Head Mound Display (HMD) and Data Gloves, which correspond to the special characters of the sensations. The characteristics of equipment now become the limitation of the realization of immersion. When the technical aspect is improved, mostly, the degree of immersion can also be improved, such as a broader vision and higher resolution of the HMD, more sensible interactive equipment, or more possibilities for locomotion.

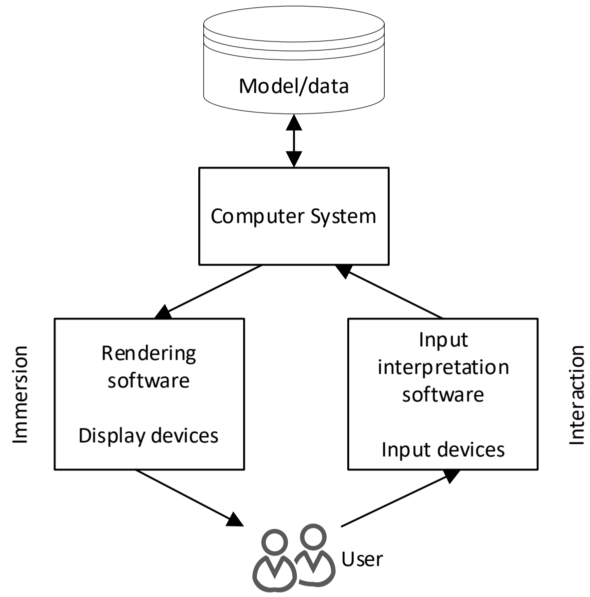

Figure 3-3 The interaction and immersion loop in VR (cf. Bowman & McMahan, 2007)

One key point of immersion is that the user can not have the feeling of being an observer in a fancy simulation of virtual reality, but rather a participant who has interactive activities in the environment. Full immersion is not a passive acceptance of gaming plots or directions, but active participation in interaction with the agents or objects in the immersive environment, which enriches the experience of immersion.

When talked about, immersion is easily related to flow and presence, which are immersive components of virtual reality. The more detailed relationships and distinctions among these elements will be discussed in the next sections about flow and presence.

3.3.2. Spatial presence

Thanks to the development of technology in recent decades, it is possible to have a completely new subjective sensation of presenting somewhere virtual rather than the real physical location through a technical user interface into a mediated world (cf. Weibel & Wissmath, 2011; Witmer & Singer, 1998, p. 225). Weibel and Wissmath (2011) suggest that presence may play a more crucial role in vivid virtual environments.

The strong presence experience magnifies both the feature of the sense of reality, which is the goal of games and movies and the feature of supporting imagination, which enables the false images. Presence is the subjective experience of being in the mediated virtual environment (cf. Oh et al., 2018). It has been repeatedly observed that people tend to, for moments, forget that they are only in a media-based illusion when they explore the new world of virtual realities (cf. Wirth & Hofer, 2008).

Spatial presence and social presence are the main types of presence in the discussion of the dimensions of presence. Spatial presence (also: physical presence and telepresence) is the extent to which one feels present in the mediated circumstances rather than his own physical location, and how much one's self-consciousness is immersing into the virtual world when the mediated contents seem real (cf. Draper et al., 1999; cf. IJsselsteijn & Riva, 2003; cf. Slater & Wilbur, 1997; cf. Steuer, 1992). Social presence (also: co-presence) is the sense of being in mediated environments as a social entity and being with another social entity (cf. Oh et al., 2018). The participants in the virtual environment exchange information or perceive emotions from the other avatars simulated by the computer or controlled by other participants. The sense of being a social entity (or self-presence) via an avatar or character in the virtual environment will be discussed in the following section about avatars and identity, as well as in the discussion of embodied cognition. According to Wirth and Hofer (2008), spatial presence is the precondition of social presence or co-presence. Technological features, contextual properties in virtual environments, and individual traits could influence the sense of social presence (cf. Oh et al., 2018).

In an international research project, "Presence: Measurement, Effects and Conditions (MEC)", a multilingual questionnaire of MEC-SPQ was developed to measure the special presence of different types of media. The validation of the questionnaire was tested with the evaluation of the spatial presence of various scenarios conceptualized in the form of videos, text, hypertext as well as virtual reality (cf. Matthes et al., 2008; cf. Vorderer et al., 2004). The researcher group proposed a two-level process model of spatial presence, which suggests the spatial situation model and attention allocation are prerequisites for the sensation of spatial presence (cf. Wirth et al., 2007). The dimension of possible actions in VR is one of the most important aspects of the spatial presence experience. The ability to control space inside a virtual environment is a novel interactivity feature of VR. The users could teleport to other places, scale the space and define how the space of the viewed frame would be, instead of only following the frame defined by designers. Attention allocation is the devotion of mental capacities to media products (cf. Wirth et al., 2007).

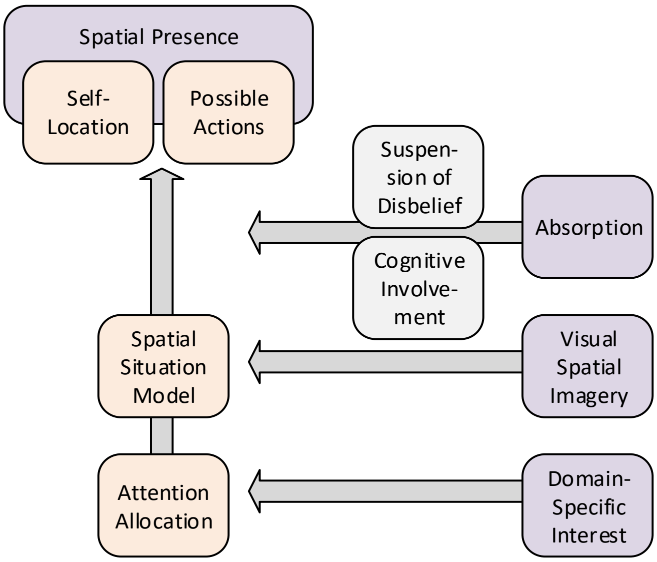

Figure 3-4 Two-level process model of spatial presence (cf. Vorderer et al., 2004)

Presence experience is a multidimensional form of perception. From the perspective of Slater et al. (1994), determinants of presence experience can be distinguished between external (= objective) determinants, such as the visual field of view, auditory and interactivity, as well as internal (= subjective) determinants, such as the inner perception and subjective experiences of the virtual environments (cf. Slater et al., 1994). For the purpose of studies in this thesis, the questionnaire of MEC-SPQ is used.

From the perspective of a designer, creating presence is difficult because of the nuanced effects of surroundings, sounds, characters, and other elements (cf. Bucher, 2018, p. 16). Comparing the spatial presence raised by the VR HMDs and standard monitors, the study of Seibert and

Shafer (2018) indicates that using a VR HMD increases the spatial presence significantly. Interestingly, the results of the study also indicate that motion sickness has no significant influence on spatial presence, which means that the participants perceive the presence experience in the virtual reality environment, in spite of the feeling of motion sickness (cf. Seibert & Shafer, 2018).

3.3.3. Identities, avatars and characters

The characteristics of identity construction in the virtual learning environment contribute to the sense of presence (cf. Fowler, 2015). In the desktop-based design, the users remain “outside” the technological environment and have fewer identity problems using throughout the application than in VR, where users are embodied normally with a virtual figure, which may be viewable as an avatar (a virtual character). A study of virtual reality identity (cf. Mottelson & Hornbæk, 2017) indicates that the user has a significantly higher sense of body ownership if the user has a consistent body with real-time body movement than without real-time reactions. Not only the self-features of the character such as sex, clothes, and movement but also a consistent environment should be suitable for the scene. In addition, the distinction between users in the same scenario is also a key aspect of the identities of users. Nevertheless, the avatar does not have to be completely the same as the real person. For example, an avatar could be only a subset of the characteristics or even as simple as a video on a screen, as long as it brings enough identity in virtual reality, which has been seen in the case of the multiuser applications with Mircosoft Hololens (e.g., Hololens Volvo Cars with multiple users).

From the perspective of sociology, communication, and design, social aspects are paid attention to in the UX study, especially in the multiplayer functional applications where users communicate and interact with others. Studies report that the collaborative virtual environment would create the Proteus effect, that the behaviors in the virtual environment of individuals could be influenced by the avatar representing themselves in the VR (cf. Yee, 2014; cf. Yee & Bailenson, 2007). The avatar shows anonymous collaborative VR environments. The avatar could be defined and decorated as similar or different to the user in the real world, including demographic features and appearance features, such as ages, skin colors, body heights, and other characteristics (cf. Bailenson et al., 2008). The Proteus effect in VR of self-representation indicates the avatar in VR could influence the self-perception and self-focus of the users (cf. Vasalou et al., 2007). The study by Freeman et al. (2014) indicates that higher virtual eye positions of people with HMDs seeing the virtual environment, which is manipulated camera position in a 3D virtual environment to show the virtual height of the characters in VR, provide more self-confidence in the social situation. Besides the theories that have a direct relation to the UX, there is also discussion about the socio-technical system, feminist, human existence and other broader philosophical framework (cf. Fuchs & Obrist, 2010).

The designer should give the user identity so that the user would know their value and their existence in virtual reality, just like in the real world. The role of the users and their identities could be changing during the events. If the identity is a student that conducts physical experiments, the interaction of the physical experiments seems more important than the other elements in VR. If the identity does not correspond to the functions or interactions, the immersion feeling of the user will decrease.

Unlike the traditional classroom teaching settings, in which the teachers could adjust the teaching methods and behaviors based on the students' behavioral patterns and the teaching experiences, the teachers should adjust the teaching behaviors to the new social interaction in the new environments. Meanwhile, there are new behavioral patterns of the students, such as the choosing of avatars and the designing of their own characters, interacting with other avatars (learners), as well as the influence on the real interaction between the students.

In the teaching and learning content, just like in the real world, the students should be in the center. No matter in VILA (Chapter 6) or in VPSL (Chapter 7), the students can explore the surroundings in VR and not be limited to one direction of view, which corresponds to the identities that they are participants instead of bystanders and viewers.

3.3.4. Narrative storytelling

The principle of storytelling in a VR application could provide a great user experience, enhancing the amusement, delightfulness, immersion, and other reactions that designers desired. In the unfolding VR, the user should follow the story script and trigger the next scene with some designing techniques. For example, instant feedback shows which elements of the environment are interactive for the exploration, the movement of objects indicates the need for attention from users, and the appearing and disappearing of sounds suggest the implied change of emotion and stories. The VR animation film "Henry" is an example, which describes the story of a hedgehog

Henry looking for a friend. In the scenario, if the user looks at Henry, he looks back at the user through his eyes, conveying that the user is his friend and awaking the empathy of the user.

In the context of situated learning in participative pedagogy, storytelling is a teaching and learning tool for a narrative-centered learning environment. From the perspective of serious games, pedagogy is infused into the user experience in the process of storytelling (cf. Zyda, 2005). Using the technique of storytelling is easier to let the user into the state of the flow experience, which is described as the optimal mental state of intrinsic motivation, being fully immersive in a highly engaging activity, time passing by, and even losing a sense of self, during which the other temporary concerns like time, food and ego are totally ignored (cf. Nakamura & Csikszentmihalyi, 2002).

Storytelling was originally a chief component of film crafting and gives the audience a believable designed story through the filming techniques and other elements in the film. With the novel technology and platform of VR, a new narrative structure and techniques would be necessary. Storytelling in the traditional film industry is connected to the cutting and view shifting of cameras. However, in VR, the cutting and camera shifting would decrease the immersion of users. Leading the users to the focus set by the designer and getting them to look where the designers want is like a magic act: the tricks of environmental storytelling are essential. For example, users tend to always look at the bright spot in the room. The spatialized audio now is easily developed with the game development engines, which is also a trick to direct the attention. A moving or animated object would also draw attention. Another great trick would be a trail of breadcrumbs in a figurative sense, arousing the curiosity of the users (Bucher, 2018, p. 39).

3.3.5. Flow

From the point of uses and gratifications theory, enjoyment or entertainment has long been identified as a primary reason for media use, which is rooted in the structural-functionalist system approach. The media flow theory indicates that exposure to media is an intrinsically rewarding experience, where the users enjoy the flow states (cf. Katz et al., 1973; cf. Ruggiero, 2000; cf. Sherry, 2004; cf. Sherry et al., 2006).

The flow theory of Csikszentmihalyi (1997) explains well the experience of activity enjoyment, which was first brought up as a psychological construct, to account for the pleasure of the immersive experience. He described flow as the optimal mental state of intrinsic motivation, being fully immersive in a highly engaging activity with time passing by, effortless action, and even losing a sense of self, during which the other temporary concerns like time and ego are ignored (cf. Csikszentmihalyi, 1997; cf. Sherry, 2004). It is an important component of immersive experience in the research area of pedagogic psychology, which has a close relationship with learning motivation. A balance between the difficulty level of the task and the skill level of the performer has to be made, and both have to be high to achieve the flow state according to nine mental states in terms of challenges and competencies in Csikszentmihalyi's flow model (cf. Csikszentmihalyi, 2000; cf. Nakamura & Csikszentmihalyi, 2002), otherwise the state will be either anxiety or boredom instead of flow. The flow state of mind gives man pleasure normally, and it also shows negative influence when the activity is impeded (cf. Csikszentmihalyi, 2000). The activities with the following features are easily led to the flow state, concrete goals with manageable rules, adjustable challenges, clear instructions, and few distractions (cf. Csikszentmihalyi, 1990).

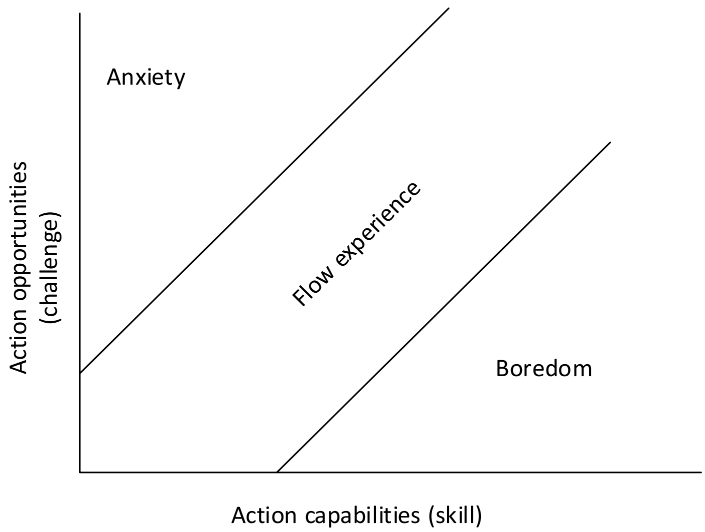

Figure 3-5 The model of flow state (cf. Nakamura & Csikszentmihalyi, 2002)

The empirical study of flow state by Csikszentmihalyi may have some problems, which has no clear differentiation between competencies and challenges during testing. Besides, the level of matching of these two dimensions, the competence and the challenge of the state, are based mostly on personal characters and situations. In the study of activities in Internet surfing, Novak et al. (2000) designed the scale of flow based on the relationship between skill and challenge, which may have similar critiques as Csikszentmihalyi's.

A topic of research might be the study of flow state in the use of multimedia methods such as computer games. The importance of flow is emphasized by Sherry (2004, p. 328) as well as Voiskounsky et al. (2004) in terms of computer games, who both point out that gratification under the theory of flow is one of the main sources of enjoyment and attraction of computer games (cf. Sherry, 2004; Voiskounsky et al., 2004). In terms of media consumption, when the learning message content matches the individual cognitive skills of students, the flow state, namely the enjoyment of media, could be engendered. Otherwise, it may be prevented (cf. Sherry, 2004, p. 328). For example, an individual who lacks the skills to use a mouse and keyboard will not enjoy the experience, and the simple and repeating tasks may also not lead to the flow state. When media messages deviate from formal norms, the flow may also be inhibited (cf. Sherry, 2004, p. 336). “Games that facilitate flow are likely to be adopted, whereas games that do not create flow are likely to be discarded” (cf. Sherry, 2004, p. 340). The flow state may be facilitated or prevented in terms of the matching situation of the two components mentioned above. Video games possess ideal characteristics to create and maintain a flow state when the challenges and the skills match each other (cf. Sherry, 2004, p. 340). Voiskounsky et al. (2004) also indicate that the experience of flow state is one of the main sources of the long-term attractiveness of a multi-user computer game. Understanding the mechanism of flow with the theory of uses and gratifications will be facilitating the design and development of the educational uses of no matter serious games or virtual learning environments (cf. Voiskounsky et al., 2004).

When adapted into human-computer-interactions by Rheinberg et al. (2003), six components of flow are summarized from the eight component categories by Csikszentmihalyi (cf. Rheinberg et al., 2003; cf. Rheinberg, 2006). Then, after factor analysis, they indicated that the construct of flow state consists of two dimensions. The first factor, the fluency of performance, refers to the utmost and unintentional concentration, the optimal feeling of controls, concrete action goals and clear feedback, smooth and logical action sequences. The second factor, absorption by activity, includes the feeling of full involvement, an altered perception of time, and a loss of reflexivity and self-awareness (cf. Rheinberg et al., 2003, p. 271; cf. Rheinberg, 2006).

With respect to the virtual reality environment, the flow experience has rarely been studied. Some researchers criticize that the full involvement in virtual reality may cover the learning purpose and lead the students to the game-playing state (cf. Lindsay et al., 2009, p. 230). In the research area of learning performance and learning motivation, the potential of flow state with virtual reality learning software is worth studying. The results of experiments show that Virtual Theatre leads to more flow, which is in line with immersion when users can have natural walking on the omnidirectional floor (cf. Hoffmann et al., 2016).

The results of experiments show that flow and spatial presence have similarities (cf. Fontaine, 2002) and positive correlations (cf. Hoffman & Novak, 1996; Novak et al., 2000; Weibel et al., 2008), but the differences are also discussed (Fontaine, 2002; cf. Weibel et al., 2008). Not only theoretical but also empirical studies have been performed to investigate the similarities and differences of flow and presence. Weibel and Wissmath (2011) highlight that presence is the sensation of being spatially present in mediated environments, and flow is the sensation of being involved in the activities. Weibel and Wissmath (2011) conduct three gaming studies and find that flow and presence both depend on motivation and the immersive tendency of users, but they rarely have common variance in the factor analysis. Besides, they suggest that the experience of flow has positive effects on enjoyment and performance, and the presence has only an indirect influence via flow on enjoyment and performance.

This section discusses the definition and the main constructs of the user experience in the virtual environment. The user experience refers to the total sense of the individual in the virtual reality at all the points on the timeline. The active sense of immersion is a multidimensional continuum in the virtual reality supported by the various hardware and software, which is related to the sense of flow experience and present experience. Spatial experience is one of the constructs that are often studied in the context of virtual environments, including self-location, possible actions, and other dimensions, because of the simulation and interactions in VR environments. The user-centered training and didactic learning design bring the identities of the individuals in VR into focus. The perception of the presence, the flow, and the emotion of learners in the VR environment would be influenced by the representation or the appearance of their owner characters and others. Therefore, the identity, avatars, and characters of the individuals should be designed thoroughly in the VR applications, which are conducted in VILA and VPSL. The flowing narrative storytelling would be the key to a dynamic combination of the immersion feeling, the perception of the spatial presence, the identities, and the avatars, which triggers the steps of the interactions and the designed processes in the scenarios.

The flow experience, the immersion in the activities in virtual reality, is a status with corresponding challenges and skills. The learners in the flow experience could immerse themselves in the activity and become a positive experience without extra effort. With respect to the learning performance, flow experience, which is a component of flow state, has positive relations to the learning performance, without considering some risking and dangerous activities like riding motorcycles (cf. Rheinberg et al., 2003). In a long-term study on the flow experiences of students in university foreign language courses, it is demonstrated that flow predicts learning achievement. Additionally, the flow experience is predicted by the learning motivation of students at the beginning of the semester. The result of the study shows that flow is an indicator of the functional state relevant to learning outcomes (cf. Engeser et al., 2005). Therefore, it is meaningful to investigate the flow experience of learners in learning activities in virtual environments. This section introduces the research on the constructs of the user experience, especially the flow experience in training and learning.

3.4. UX Design: iteration and agile development

Usability engineering is a developing method of IT products based on user-centered design. In the context of usability engineering, the usability of software should match some key designing principles, including the early focus on users and tasks, empirical measurement, and iterative design (cf. Gould & Lewis, 1985). One of the practices of interactive development is the concept of Lean UX, which is a working system of agile project development, aiming at delivering a great user experience in a relatively short period of time or a short, interactive cycle (cf. Gothelf & Seiden, 2016).

A feature of Lean UX is the close relation between hypotheses and proofs. The proof process of the hypothesis, namely the evaluation of the user experience, should proceed with a simple, functional prototype instead of waiting for the completed project. The concept of the minimum viable product (MVP) requires building the simplest version of the idea and rapid experimentation, maximizing the resources, and avoiding unnecessary costs to find a productive way (cf. Gothelf & Seiden, 2016; cf. Steimle & Wallach, 2018).

The principle of design thinking requires “the harmony in the working system of designers, developers, product managers, quality assurance engineers, marketers, and others in a transparent, cross-functional collaboration that brings non-designers into the design process”, "relying on the collaboration, iteration, making, and empathy as core to problem-solving" (cf. Gothelf & Seiden, 2016). The developer or the engineer is no longer isolated from the practical facets, but in the team and works collaboratively for the next iteration.

Based on the Lean UX process of Gothelf and Seiden (2016) and other UX process models (cf. Steimle & Wallach, 2018), Figure 3-6 shows an overview of the UX process, including the process of ideation, concept design, prototypes, and evaluation.

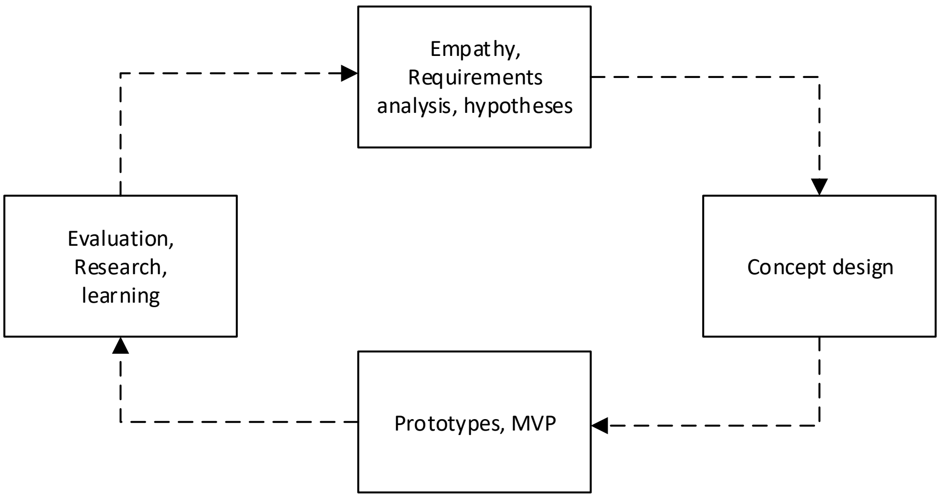

Figure 3-6 UX process (cf. Gothelf & Seiden, 2016)

In the empathy process, the requirement analysis would be conducted by the teams, declaring assumptions and hypotheses. In the concept design process, collaborative design should be conducted, building a shared understanding of further development. In the prototyping phase, the teams create the Minimum Viable Products (MVP) in a short time with paper prototypes, low-fidelity or high-fidelity mockups. In the evaluation phase, various experiments could be conducted to test the hypotheses, get the feedback and incorporate the feedback into further iterations (cf. Gothelf & Seiden, 2016; cf. Steimle & Wallach, 2018). There are a considerable number of user experience methods for researchers, developers, and designers to investigate the definitions, design the interaction processes, evaluate the prototypes, study the market, and other goals of their works. From the sea of UX methods for validation, we will discuss some highlights of the methods.

3.4.1. Requirements analysis and concept design

The virtual reality environment should aim at practice. According to Rogers (2011), some theories developed in laboratories are unfit or not broad enough in the complex real world. Therefore, researchers should derive "wild theories" from studying situations in real life instead of in laboratories. He suggests the researchers should address more interdependencies between designs, technological, methodological, and behavioral aspects instead of focusing only on the theoretical framework of designs. Traditionally, teams are given requirements and should produce products that meet the requirements. However, for the UX designer, it is important to understand the users and find the corresponding user group. To design and develop the functional application, requirement analysis is the first task, investigating the goal of the design.

The target user analysis includes the aspects of demographics and psychographics, which help to focus on the design and development of the right audience with effective content.

To describe and define the target market of an application, the methods of personas and use cases are useful. Personas are fictitious user characters or user prototypes with the characteristics of target users. The designers of products simulate and analyze the goals, behaviors, and views of the users and construct an abstractive and typical user description for the design and strategies of the products (cf. Pruitt & Grudin, 2003).

In system engineering, a use case is a concrete application process, which describes how the users achieve the goal of the system. The various users have different requirements for the application. A use case offers the details of settings and interaction processes for the interaction in the application for a special user group. The technique of contextual inquiry is also used for design and investigation, in which the researcher watches how the user would normally act and discusses it with the user (cf. Beyer et al., 2004; cf. Holtzblatt & Jones, 1993). With the data from the interview and discussion with users, the scenarios could be designed for the visions in future 3D applications.

The experience map has similar features of the methods of the use case and the cognitive walkthrough based on a timeline. It is a further observation and further guess of the behaviors of potential users. It describes how a user would behave and react to the system from the start to the end of the scenarios, providing the appropriate and practical advice for further design and development.

Using these methods described above, the designer would have a clear clue of target groups and applied scenarios. No matter it is with brainstorming or card sorting, importing the stakeholders into the designing process is the feature of participatory design in order to create the real needed product. The user acceptance before, during, and after experiencing the technology is also important for the evaluation of systems, helping to realize the resistance of the users and to reduce the potential problems. In 1989, the Technology Acceptance Model (TAM) was introduced for the acceptance of computer systems by managers and professionals, with the two beliefs of perceived usefulness and perceived ease of use (cf. Davis et al., 1989). Later, the hedonic constructs of the technology were imported into the acceptance evaluation system (cf. Hassenzahl et al., 2003). With the increasingly high immersion of users into the technological world, some new methods emerge in both research and industrial fields.

In the communication process or the designing process, there are some practical methods for the designer to output the ideas and deliver them to the programmer successfully. Concerning the immersive and full-angle features of VR, some of the methods from the movie industry would be helpful.

A storyboard is a series of illustrations or images, including the motion and animations in the scenarios that designers design. It is a simple and clear way with pictures to show the storyline of the application when a user comes into virtual reality. Paper prototyping also concerns the low-cost and easy description of the application with the low-fidelity pictures of user interfaces and environments in virtual reality.

Paper prototyping is often used as an efficient tool for communicating with users, especially with applications with sufficient functions on the modern interactive smart tablet (cf. Snyder, 2003). The illustration with pictures is often used in the movie industry instead of computer science before virtual reality becomes popular. Now the scenarios in virtual reality bring the picture-description into the virtual reality design because of its convenience to show the designing concepts (cf. Arnowitz et al., 2007).

In most cases, the elements in VR closely related to the goal of the application should be as accurate as possible, while the irrelevant elements do not have to be; that is what the designer should balance for the efficiency of the development. From the aspect of validity, how sophisticated the application would be is the first question to answer before the design starts. The VR equipment could be as sophisticated as the body-tracking optic system or as simple as the Cardboard, made of hardboard and two optic lenses. The trade-off between the virtual experience that the hardware could bring and the popularity of the application would be taken into consideration. The deeper thoughts of UX design include whether the user has enough space to set the system, whether the user could afford the cost of the product, whether the user could start the system in a few seconds, or they need an undisturbed environment with a long introduction, and whether they could handle the system errors when the technology fails.

In addition, there is some add-on technology that can be added to the existing setups, such as a headset microphone for a better and non-disturbing audio environment, data gloves for a more sensitive interaction, and eye-tracking devices for the recording of eye movement for more precise analysis. Some of the decisions could be made based on formal experience, while others should be tested in the iteration of the development processes.

3.4.2. Prototypes and evaluation methods

In the UX process, it is necessary to create an MVP or a prototype after the hypothesis and the concept design are finished in order to make the decision among all the varieties. For example, in virtual reality, navigation could be realized with in-place walking, teleportation, and other navigation methods. The decision could be made through the results of the iterative experiments, and the outcomes of iteration could provide evidence as to whether the direction of the design was correct.

In the creation of an MVP for validation, the evaluated goal should be clear in order to get the important data for the products, and the irrelevant surroundings should be left for the next iteration. The MVP should be as small as possible because the process is iterating and modifying (cf. Gothelf & Seiden, 2016, pp. 75–80).

The level of fidelity of the prototypes should be based on the audience for the prototypes. If the prototype is demonstrated to the engineering in the team, there is no need to demonstrate all the irrelevant facets of the current issues. The rapid iteration and duplication would be easily arranged and easy to evaluate. Otherwise, if the audience is not familiar with the product, a greater level of fidelity for the prototype would provide a better understanding and get, therefore, effective decisions with the detailed interaction, visual design, and content. The high quality of the high-fidelity prototypes would also be time-consuming (cf. Gothelf & Seiden, 2016).

With the growing number of virtual learning software and platforms, there is a wide range of evaluation methods available to evaluate the prototypes of the artifact learning virtual environment. The evaluation of educational settings is important for educationalists to guide the development or improvement of the virtual learning environment. Perspectives in the evaluation of the virtual learning environment include the individual perspective of the learning process in the environment, the system perspective on the technical equipment as well as the didactical perspective focusing on the technical integration into the course context (cf. May et al., 2016).

Although the hardware in the virtual reality field develops and changes dramatically, the UX research principles and techniques remain consistent. From the principle of Lean UX, the research phase should be continuous, building the research process into the sprints, and collaborative, building the research with the other members of the entire team. The validation of the prototype should be early in the development process. The criteria for the evaluation of the results should be clear before the test of the prototypes. In this phase, the goal of the validation is not a marketing publication but constructive feedback for further iteration (cf. Steimle & Wallach, 2018). There are many methods for UX designers, UX researchers, and developers to get feedback from the users to see if the product is appropriately designed. The examples of the various channels through which customers can provide feedback are shown in the diagram (Figure 3-7) indicated by Gothelf and Seiden (2016), some of which will be further described in the following sections. The evaluation after the vast release would not be helpful because the feedback comes too late. The interactive development with the evaluation of each increment of the product development gives the designers and developers timely feedback for the next iteration.

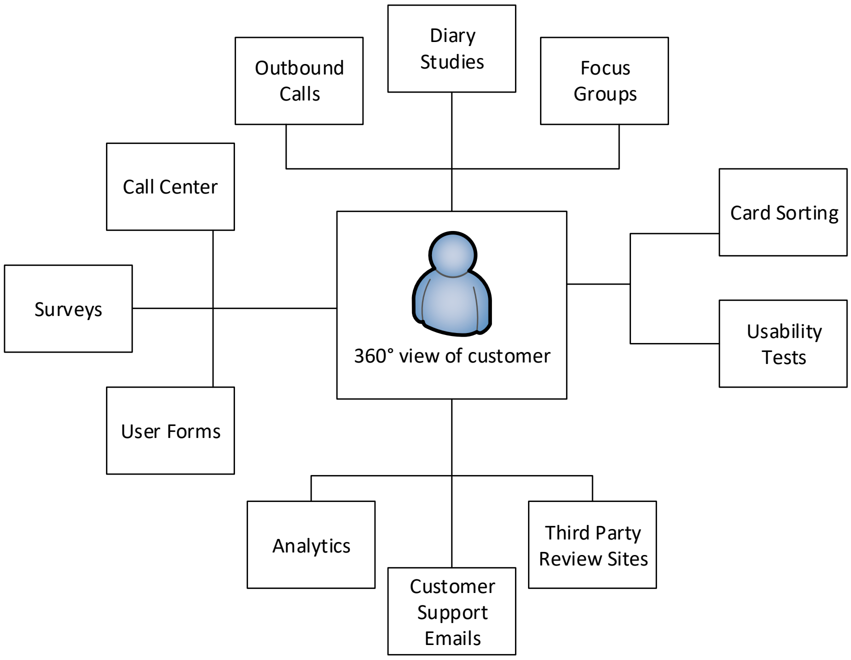

Figure 3-7 Monitoring techniques for design and research (cf. Gothelf & Seiden, 2016)

The following schema shows the UX evaluation methods presented in different dimensions, attitudinal versus behavioral, as well as qualitative versus quantitative, based on the dimensions of Rohrer (2014) and Steimle and Wallach (2018). The behavioral methods describe the behaviors of users with objective data. The A/B-testing presents two varieties of design and offers effects on the behaviors of the users, and the eye-tracking method measures the effects of visual interaction on the behaviors. The self-reported (attitudinal) information is also useful to the designers, which provides insights into the mental processes of users. The self-reported questionnaires measure quantitative data about the attitudes of the users, which can help discover important issues. Additionally, the qualitative versus quantitative dimension indicates whether the data is directly measured through observation or indirectly collected through the survey or an analytics tool.

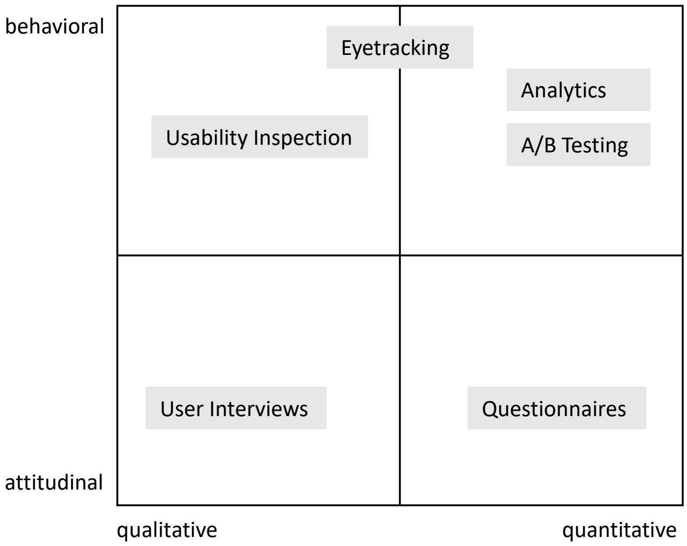

Figure 3-8 Different types of evaluation methods (source: own presentation)

The team would also benefit from combining multiple methods. For a detailed user observation with a few participants, usability tests would be suitable, such as heuristic evaluations with experts and cognitive walkthroughs with customers. If the population of participants is enough, the A/B-testing and analytics could be conducted for quantitative analysis. The user interviews provide the attitude of the users towards the user experience. The survey of the usability questionnaire methods could be used for the quantitative analysis of enough testing participants.

3.4.2.1. Heuristic evaluation

Heuristic evaluation and cognitive walkthrough are two commonly used usability testing methods in a laboratory to find invisible problems. The participants conduct the test of the products with clear goals. When the goal has not arrived, a usability problem appears. The participants are given a set of scenarios of tasks and usage of the specific interest within a product or service (cf. Rohrer, 2014). In usability evaluations, neutral findings are to be noted, no matter if they are positive or negative results.

As with any new medium, learning what does not work will be just as significant as learning what does (cf. Bucher, 2018, p. 19). One of the UX inspection methods is heuristic evaluation, which is a whole principle about the interaction design, providing quick and inexpensive feedback in the early development phase. Virtual reality systems may suffer from severe usability problems like conceptual disorientation or inability to manipulate objects, leading to a need for usability evaluation of virtual reality platforms and a better immersive virtual display application (cf. Bolas, 1994). Nielsen (1993) provided heuristic evaluation as an effective approach for usability evaluation, and cooperative evaluation provided by Monk et al. (1993) is also an alternative for usability evaluation.

The evaluation is mostly an expert review, which could discover the undetectable point and maybe offer the possible correctness measurement to designers with the correct heuristic processes based on the experience of the experts. However, it may focus on the minor details that are unnecessary for the several first rounds of prototype development. Neilson proposed that an in-house user test with 5-7 participants would be enough for a heuristic prototype test (Molich & Nielsen, 1990; Nielsen, 2000), with their thinking aloud, including negative as well as positive feedback from the users. The analysis should also include positive feedback with negative feedback. Nielsen (2000) conducted studies with small groups using iterative design, using the same investment of time and money to test the multiple iterative versions of the product. The designer could achieve the greatest improvement in the product through increasingly deep and concrete iterations of designs and tests, finally within the investment constraints.

3.4.2.2. Cognitive walkthrough

Cognitive walkthrough is also a heuristic method that focuses on interactive systems, requiring the user to follow a predefined sequence of interactions or to complete a task (cf. Spencer, 2000). The designers walk through the steps of the sequences and report on any potential issues, checking whether the users will notice the information, accomplish the task, and receive appropriate feedback. According to the consensus of the usability community, it is basically an effective but simple method for the developer to identify the potential problem or conflict of the training module with operational procedures in a short period of time (cf. Wharton et al., 1994). The common misuse or misunderstanding of cognitive walkthrough would uncover more issues than the actual testing users because of the deep knowledge of the application (cf. Blackmon et al., 2003).

Cognitive walkthrough plays an important role in usability engineering (cf. Lewis et al., 1990). Based on the interaction model of Norman (1986), which is the foundation of the cognitive walkthrough method (cf. Sutcliffe & Kaur, 2000; cf. Wharton et al., 1994), developed an extended walkthrough approach to describe users' mental and physical actions in 3D worlds, facing the new problems posed by VR and specific designs, such as navigation, orientation, and movement. The walkthrough procedures are divided into the main task-action cycle and two sub-cycles, navigation and system initiatives.

3.4.2.3. Usability questionnaires

The feedback and designing decisions in time are essential to the development. A prototype with low fidelity is often enough for a usability evaluation when the goal of the usability test is clearly set in a typical application scenario. One of the measuring methods of usability of software applications is the post-task usability questionnaire, which can provide diagnostic information about the software applications and give usability feedback immediately and comprehensively after the task, increasing the validity of the tests (cf. Sauro & Dumas, 2009). The following are some popular usability questionnaires as examples. When we first finish a functional prototype of the virtual reality training application, user testing is unavoidable for better optimization before further development. As a non-functional attribute, usability cannot be directly measured. Instead, it can be measured by means of indirect indices like the objective error reports or the subjective evaluation of users. Although the knowledge of HCI (Human-Computer-Interactions) helps the accuracy of evaluations, they can be carried out by individuals without HCI training.

Due to time constraints, a dirty and quick questionnaire, the Software Usability Scale (SUS) was developed by Brooke (1996) and used widely. Another of the post-task questionnaires is the After Scenario Questionnaire (ASQ), which includes three rating scales in a Likert scale format, exhibiting acceptable reliability and sensitivity (cf. Lewis, 1991). Usability Magnitude Estimation (UME) was created to overcome the disadvantages of Likert scales with a ratio of different ratings, especially for the subjective dimensions of complex physical stimuli (cf. McGee, 2004). The mathematical formula makes the UME more burdensome than the other Likert scales questionnaires. However, the participants in some studies may ignore to make the ratio judgments (cf. Sauro & Dumas, 2009). In their study, the Subjective Mental Effort Questionnaire (SMEQ) is also compared, with a drawn line indicating how much mental effort is invested in executing the task (cf. Zijlstra, 1993). The results of studies involve that the Likert question is easy for participants to understand and easy for an administrator to set up, and the SMEQ has good overall performance as well. However, the UME is less sensitive than the other question types (cf. Sauro & Dumas, 2009). The designers should take the time constraints, suitability, and other restrictions of all the usability questionnaires when choosing the questionnaire or deciding to develop the questionnaire themselves.

3.4.2.4. Eye-tracking

Because of the possibilities of interactions with VR equipment, the recording of body movement, head, and hands tracking, looking at directions, looking at the time, even heartbeat and pulse help to complete the evaluation of the VR applications.

Eye-tracking is one of the most advanced user testing technologies. Normally the data that eye-tracking records would be the fixing points, fixing time, the movement route of the fixing point, as well as the interaction with the environment. From the user experience part, it is helpful to directly and objectively show whether the participants are missing some key elements or whether the participants focus on some irrelevant points, based on which content attracts the attention of the users (cf. Duchowski, 2007; Patle et al., 2019; Sharma et al., 2016). Additionally, the movement route of eye fixing points can also indicate to some extent whether the users follow the learning strategies set by the designer step by step and accomplish the goal of the training. Pettersson et al. (2018) used an eye-tracking system (Tobii Eye Tracking VR Devkit) to evaluate the general cognitive ability with Raven's progressive matrices (RPM) in a VR environment, expanding the toolbox for researchers and improving the accuracy of the results.

In addition to the method of eye-tracking, the records of heartbeats, pulse, breath frequency, and other technical detections also have the possibility of evaluating the reactions of users in the virtual reality environment (cf. Dörner et al., 2013; cf. Slater et al., 1994).

3.4.2.5. A/B testing

A/B testing is a quantitative measuring method consisting of experiments with two or more variants of the concepts in order to compare which of two or more similar concepts could achieve the goal more effectively (cf. Gothelf & Seiden, 2016). The variants of the concepts are presented to different users. For example, version A is the current release (control), and version B is the modified release (treatment). The performance of both versions would be compared, and the results would be used to test the raised hypotheses. The modification of the compared version should be as small as possible for the designers to get a precise comparison. The tool of A/B testing is inexpensive and could be applied in many contexts. The A/B testing methods are useful when pursuing a specific goal, such as pursuing a clear result. However, the combined influence would be ignored, and it is not applicable when the final goal could not be defined as A or B, with the limited testing options.

3.4.2.6. Emotion analysis

The impact of immersion and presence experience in VR would have a significant influence on the emotional reaction of users, which has already been proved in various psychological VR applications (cf. Riva et al., 2007). Twenty years ago, VR presented its potential to support specialty health care and psychotherapy (cf. Riva, 2005). For example, virtual reality exposure therapy has been studied and is becoming an increasingly common application for anxiety and specific phobias (cf. Parsons & Rizzo, 2008).

Concerning the educational and industrial application context, the aspect of emotion raised discussions in terms of the user experience. Emotion influences the use of cognitive resources, learning motivation, or the efficiency of self-regulation. Positive emotions benefit the learning effects (cf. Hascher & Edlinger, 2009), and negative emotions, such as exam anxiety, have a negative correlation with the concentration of the students (cf. Frenzel & Stephens, 2017; cf. Krapp et al., 2014). No matter if it is a website, software, or a VR learning and training application, emotion analysis is an evaluation system that needs attention. From the perspective of pedagogical psychology, the virtual reality environment, as a 360-degree full-dimensional environment, has far more aspects than normal desktop-based software that have an influence on the emotions of users, such as learning motivation and learning interest (cf. Diemer et al., 2015). Additionally, the nuances of light, shadow, colors, and even facial expressions on the avatar in the virtual surroundings have effects on the mental changes of users (cf. Agarwal & Meyer, 2009). The solid choice of the VR elements should be chosen based on the particular scene, but it is necessary to take emotional effects into consideration during designing and evaluating in any case.

The established meaning of objects in VR has crucial emotional connections with the viewers in VR worlds. The research on the effects of embodying self-compassion on patients with depression in virtual reality highlights that interventions using immersive virtual reality may have considerable clinical potential for patients with several physical and psychological disorders (cf. Falconer et al., 2016).

Table 3-1 Approaches of UX evaluation for VR environments (source: own presentation)

Approach	Characteristics	Potential advantages	Potential disadvantages
Heuristic evaluation	Usability testing, expert review	Effective with a small group, easy to discover the undetectable points, possible to find the solution to the problem	May focus on the minor details in the starting phase
Cognitive walkthrough	Usability testing, developer review, a specific sequence of tasks	Effective but simple, useful for the interaction system	May focus on the minor details by the developer
Usability questionnaires (Survey)	Post-task questionnaires, various kinds of scales	Immediate and comprehensive	Time constraints
Eye-tracking	Physiological recordings,	Direct and objective measurement, showing the cognitive process	complex in analysis
A/B testing	Experiments with two or more variants	Clear results	Only one goal and no long-term behaviors
Emotion analysis	Immersive influence of VR	Corresponding to VR features	Too many influential factors

The table above outlines the application fields and the limitations of the common methods for UX design, development, and research. After the validation and evaluation of the product, decisions should be made for the next iterative cases or iterative development steps (cf. Steimle & Wallach, 2018). There are also many other methods to evaluate the user experience. The mentioned methods are only the methods that could be appropriate in the context of learning and training in virtual reality.

This section discusses the user experience in virtual reality from the perspective of design and development. Since there is the experience in technological design and development in the field of computer science and engineering, some methods of requirements analysis, conceptual design, prototype development, and evaluation could be used for reference in the case of VR. The principle of iteration and agile development would be an effective method to arrive at the goal of virtual learning scenarios. With the iteration of development and evaluation in cycles, the application would be improved in every cycle. In the requirement analysis, the methods of personas, use cases, and the experience map would give the designer a concrete clue about the scenarios. The methods of the storyboard and the paper prototyping help the designer with the concept design with the low-fidelity illustrations. After a prototype of an MVP, evaluation is necessary. The evaluation methods that are suitable for the virtual training and learning environment are listed in this section with their features, advantages, and disadvantages, including the methods of heuristic evaluation, cognitive walkthrough, usability questionnaires, eye tracking, and emotion analysis.

3.5. Interim conclusion to user experience in virtual reality

In this chapter, the definition of user experience, usability, and user interface are outlined. The constructs of the user experience in virtual reality are looked at, including spatial presence, flow, immersion, and other features in VR, highlighting the research focuses of the empirical studies in this research. The introduction of the user experience in this chapter covers the thematic areas: immersion, spatial presence, identities and the representation of the self, the narrative storytelling, as well as the most important construct, flow experience, some of which are empirically examined in Study I and Study II.

The iterative and agile design and development principles focus on the thematic questions: training and learning content, the technological context, the participants of the applications, the using scenarios of the application, as well as the cycle between the development and the evaluation of a virtual reality application. The user experience design and developing methods are discussed, including the UX processes of requirement analysis, concept design, prototyping, and evaluation. The features, the potential advantages, and the potential disadvantages of the various evaluation methods are analyzed and listed, which are mostly applied to the user experience in a virtual training and learning environment. These techniques, used in conjunction with the technical aspects of the virtual reality technology in Chapter 2 and the learning theory in the following Chapter 4, give an outline of the design, development, and research of the learning application in VR and guide the design, development, and implantation of the learning and training applications in the following practical studies in Chapter 6 and Chapter 7.

4. Learning in Virtual Reality

Although the application of virtual reality technology to create a training and learning environment is promising nowadays, the pedagogical underpinning is of great importance and is often ignored in the design and development of the application. Learning theories support the fundamental construction of the design and development of learning scenarios. Before the combination of new technology and practical training and learning scenarios, it is necessary for researchers and practitioners to consider the appropriate way to take advantage of the features of the new technology based on the foundation of learning processes (cf. Zinn, Pletz, Guo, & Ariali, 2020).

The approaches of the design and development of the VR environment could be a combination of approaches from the theoretical perspectives of behaviorism, cognitivism, and constructivism. Fowler (2015) proposes a design approach for learning in the 3D environment, focusing on the learning activities, the learning stages, the learning outcomes, and objectives, as well as the related technical environments. The learning context, including the locus of control, the group dynamics, teacher dynamics, task authenticity, level of interactivity, and source of information, helps to build the appropriate teaching and learning approach, together with the learning requirements, that are based on the stage of the learners and the pursued learning outcomes (cf. Fowler, 2015). From the perspective of the design of the user experience in the training and learning VR environment, the design of a learning environment also focuses on the iteration and agile processes, with requirements analysis, concept design, prototypes, and evaluation methods.

The preceding chapters have been primarily based on the technological perspective; this chapter will focus on the pedagogical considerations in 3-D environments. The learning process and learning theories, along with the consideration of the application of virtual reality, will be discussed in this chapter. Based on the description of various virtual learning environments as well as the analysis of the user experience and its concrete constructs in the previous chapters, this chapter, through the definition and identification of various learning environments and learning software, underlines the importance of the didactical design with respect to the learning experience and learning outcomes in VR environments.

4.1. Learning processes in VR

4.1.1. Behaviorism

Based on the assumption that behaviors are created as the response to certain stimuli or as the consequences of the reinforcement or punishment of the stimulus-response association of the learners, behaviorism focuses on the environmental factors that can influence the individuals (cf. Watson, 1994). For instance, in the simulated virtual environment, the interaction between the learners and the objects in the environments could provide instant feedback, based on which the learners could decide the next learning steps and establish an association between the knowledge and the feedback.

The research on “the control of operant behavior” in a “Skinner box”, that is an operant conditioning chamber by the American psychologist and behaviorist Skinner, demonstrates how the reinforcement of the operant modifies the stimulus-response-consequences mechanism. He described that the learning procedure needs precise instructions that are broken into steps with increasing difficulty and the feedback as intermittent reinforcement to keep the performance (cf. Catania, 1988; cf. Krapp, 2014). The research on radical behaviorism raised by the American psychologist and behaviorist Skinner suggested that the organism’s covert behavior, including cognition and emotions, has significant value to the future environment and performance as a reinforcement. Additionally, there are also many studies that prove that teachers can use encouragement methods to reinforce positive actions and use the absence of reinforcement to minimize the negative actions of students (cf. Krapp, 2014). The classic behaviorists prior to Skinner argued that the inner interest and motivation have little effect on the students’ behavior (e.g., cf. Watson, 1994) and focused only on the behavior of the learners, which was already criticized by researchers (cf. Baumgartner & Payr, 1998, 1999) for ignoring feelings and emotions and the resulting problem of knowledge transfer, when the learners simply recite the learning content without comprehension.

Behaviorism after Skinner provides some useful perspectives for the design and development of interactions and the environments in virtual reality. The theory of gamification of E-learning was developed using the theory of reinforcement. The scores, progress bars, and other evaluations of learning systems, such as the tests on the platforms of massive online learning courses, functions as the external stimuli for the learning process.

In the programmed virtual environment, the interactions between users or users and objects provide an instant stimulus, leading to the next step in the learning process. How to convince the students that the crafted virtual reality world is functional may be a question of behavioral science. Interaction with the objects in the virtual environment should not be so direct or compelled that the user must follow the leading of the ideas of the designer. It is a relationship between the user himself and the characters, the objects, the animations, and the surroundings around him (cf. Bucher, 2018, p. 10).

4.1.2. Cognitivism

From the perspective of cognitivism, learners store and organize knowledge through learning processes and build the cognitive structure. From the perspective of cognitivism, learning is not through reinforcement, but through thinking actively and independently without outside stimulus (cf. Blümel et al., 2010). The learning process is the interaction between existing knowledge structures and new information data, and the circulation of assimilation and accommodation (cf. Köhler et al., 2008, p. 483). The extraction of information by the learners themselves from the sea of information, the assimilation of the new perception into the existing schemas, the building of the knowledge structures, and the learning motivation of the learners are the key factors of the learning processes (cf. Nückles & Wittwer, 2014). In virtual reality, the virtual environment has abundant scenarios and objects, with control in the hands of users, which indicates the assumption and practice of Piaget (2003), the integration of meaningful simulation and tasks in learning settings.

From the perspectives of development of competence, the interiorization process of knowledge as well as the characters of the knowledge in vocational education, of behavior experience, declarative and procedural knowledge, that the actions build the starting point of the development of thoughts (cf. Aebli, 2011; cf. Blümel et al., 2010). In the design of the virtual reality learning scenarios, the interaction and simulation should be based on the learning experience and knowledge backgrounds of the learners to promote the development of cognition and aim at the enhancement of the internal motivation and intrinsic interest of the learners to lead to the exploration, questioning, and cognition in the virtual environment.

The limitation of cognitivism was also proposed by researchers. Cognitivism usually treats information processing during the learning processes as explanatory models or patterns, which are built in the context of the laboratory. Cognitivism focuses on objective entities and their relationships, ignoring individual internal processes (cf. Holzinger et al., 2008). Therefore, the further developed philosophy of education of constructivism was proposed.

4.1.3. Constructivism

This thesis concerns not only technical innovation but also the development of new learning forms, namely, digital didactical design. As Jahnke (2016) defined in her book, the digital didactical design is the perspective and activities of reflection and a cultural change in the design of teaching and learning with materials and content (cf. Jahnke, 2016). The "shift from teaching to learning" (cf. Barr & Tagg, 1995; cf. Richter, 2005) is one of the goals that we pursue. From both cognitive and constructive perspectives, the center of the project is the students and their learning processes.

Constructivism is one of the basic and most applied learning theories in the educational application of VR. In accordance with the constructivism paradigm, students are confronted with accessible and authentic mixed reality training situations. Learners generate knowledge and experience in the closed information system spontaneously based on the interaction between prior knowledge and experience in real laboratories or other working spaces, not from the teacher exclusively (cf. Baumgartner & Payr, 1999). It is not enough when the designers put only the learning content into the mixed reality environment. In order to get better learning effects, the learning activities should be geared to digital mechanics (cf. Le et al., 2013). From the theory of the ludic constructivism of Wagner and Wernbacher (2013), the learning results are also based on the "translate competence" between meaning contexts of objective reality and median virtual space in the existent rules and goals of virtual gaming processes.

In the case of radical constructivism, learners, as a closed operational system, do not uncover the real reality; instead, they build their world with the interaction between the new and old experiences. In contrast with radical constructivism, cognitive constructivism suggests that to construct the new structure of knowledge actively, learners build the connection between the stimulus from the environment and the available cognitive structure to modify their existing intellectual framework and accommodate the information appropriately. In a computer-based learning environment, which is the premise of constructivism, knowledge should be constructed independently by the learners instead of transmitted through the instruction of teachers. The teachers will serve as coaches, who support and encourage the learners (cf. Baumgartner & Payr, 1999). The teacher involves the learners to improve their new knowledge structure with the alternative experience and knowledge, and the learners discern the relationship of a complicated situation and generate the problem solutions, using the alternative experience, feelings, behaviors, lifestyle, and communication (cf. Dittler, 2003). The learning process is about not only the psychological condition of success, the actual result and planned result, but also the social interaction with others (cf. Hoffmann et al., 2016).

The theory of social constructivism by Vygotsky suggested the "zones of proximal development," which is understood as space where learners cannot complete the task without help but can complete the task with the guidance of other knowledgeable instructors (cf. Cole et al., 1981). The learners get involved with the knowledgeable instructor in their lives through social interactions and develop the ability to complete the task independently.

In the field of vocational education, situated learning was proposed for the training of tacit skills like the competencies of butchers, midwives, and tailors through experience and modeling, where the learning process happens in the workplace with practical tasks (cf. Lave & Wenger, 2011). Situated learning is not limited to cognitive processes. It concerns the created situation and the environment of the learning that the students would be facing in the future when they are in the real working environment. In situated learning, the students are more likely to participate actively in the learning experience. Through the realistic environment, the learner understands the value of their work and knowledge to learn and assimilate it actively and effectively. The evaluation could be parallel to the learning by observations or context-driven evaluation. Based on the holistic and realistic problem, the internal motivation would be caused, the exploration spirit of the learner would be promoted, and the problem-solving competence of the learner would be cultivated (cf. Lave, 1991). The concepts of "cognitive apprenticeship" and "anchored instruction" are proposed, originated from the principle of situated learning.

Cognitive apprenticeship, in line with the theory of zones of proximal development, reflects the situated cognitive theory and suggests that the learners work in a team with the scaffolding of the instructors. Immersed in the practical environment, the learners acquire the knowledge and skills through social interaction and understand the networking of problems and solutions, focusing on the reasoning process, cognitive and metacognitive strategies of the instructors (cf.

Collins et al., 1991; cf. Collins & Kapur, 2009). With the approach of cognitive apprenticeship, technologies with simulations with videos, audios, and images would be helpful, which is not a drill-and-test program, but a resource set that the learners can extract information from. In the program, the use of the program should be monitored by the instructors, and the hints and prompts should be supported when the learners need help.

Anchored instruction is also an approach under the paradigm of constructivism. Anchored instruction requires the learners to experience the tasks in the authentic scenarios themselves instead of only listening to the introduction by others. The realistic task or case would be the anchor of the learning process, and the learners would find the clue to solve the problem based on the hints that the instructors give. The cooperation between learners, as with the other approaches of constructivism, is also a critical phase for the learners to deepen their understanding of the knowledge. The evaluation is based on the problem-solving process itself (cf. Bransford et al., 2012; cf. The Cognition and Technology Group at Vanderbilt, 1993).

In virtual reality with 360-degree simulation, learners experience the learning process like they are in the real factory from various perspectives, enunciate and reflect on the knowledge structures, and generalize the learned content (cf. Köhler et al., 2008, p. 484). In addition, the operations and introductions for the learner can also be simulated with 3D modeling and animations. The cooperation and communication between the learners, which is also crucial in the approaches of cognitive apprenticeship and anchored instruction, can also be realized in the virtual environment with the help of synchronization of videos, audios, and animations of the learners.

Nowadays, technologies will always be part of the learning processes that create scenarios and construct learning models. However, the whole learning design should not ignore the teaching and learning content and plans and only focus on the knowledge that needs the methodologies of building the scenarios. Teaching methods with high technology are not appropriate for every kind of knowledge. Otherwise, there would be an inconsistency in knowledge transfer. The role of the instructors could not be replaced by the technologies, especially considering their functions in the zones of proximal (cf. Holzinger et al., 2008). The research of Anderson et al. (2000) indicates that effective learning strategies or learning plans should include the combination of both individual cognitive perspective and constructive social perspective learning. The cognitive approach is not denying the value of group activities and situative effects, and the constructive approach is not ignoring the value of individual working. Both perspectives provide important aspects for analyzing the learning processes, and both should be pursued vigorously (cf. Anderson et al., 2000).

4.1.4. Embodied cognition

With the development of virtual reality, the theory of embodied cognition, one of the new research fields of psychology, is more often used in explaining the effects of the environment and body movement. The theory indicates the strong connection between physical and psychological situations. Embodied cognition emphasizes the function of the body in the cognition process. Wilson (2002) addressed six views of embodied cognition: cognition is situated; cognition is time-pressured; we off-load cognitive work onto the environment; the environment is part of the cognitive system; cognition is for action; off-line cognition is body-based.

VR incorporates the participants into a virtual world bodily. Based on the theory of embodied cognition, learners do not play a passive role in the learning process but combine with the environmental factors, which are not an additional factor but combined with learners as a whole (cf. Shapiro, 2011). It is argued that the immersive VR is perceived through natural sensorimotor activities, such as head-turning in the direction of vision, looking around the environments, reaching out with hands to the virtual interactive objects, body turning to the objects or the other characters, looking at the detailed characters, and other natural sensorimotor activities that are similar to the normal perceptual methods in the real world. Additionally, the computer-generated character from the first perspective, which is synchronized to the body movement of the participant, produces the body ownership illusion of the participants (cf. Slater, 2017).

For example, the learners of the new generation who grows with the increasingly developing technology like computer, laptop, smartphone, and internet, have already built the new learning method or thinking mode with the environmental factors integrated. Therefore, creating a learner-centered and technology-supported environment, where learning methods and learning motivation are considered, is the production goal of learning in virtual reality in this information era. The intelligence of humans lies less in the individual brains and more in the dynamic interaction of brains with the outside world. Embodied cognition may be the focus of a further step in the development of artificial intelligence (cf. Anderson, 2003).

The study of Johnson-Glenberg (2017) with the learning content of a virtual experiment of the electric field varies the level of the embodied condition from no embodiment (reading text and symbols), a low embodied condition (watching pre-created animation and simulation), a high embodied condition (interacting with body movement with motion capture technology) to a high embodied condition (body interacting with narrative scenes). The results of the study indicate the benefits of being active and embodied in the learning processes, and a sensible and embodied assessment of the embodied study should be developed that also assesses in an embodied way (cf. Johnson-Glenberg, 2017).

The project HandLeVR designs and implements a virtual 3D learning environment for the automobile varnisher in vocational education. The learners in training would use a sensor-equipped tangible input device as the paint spray in the VR simulated application (cf. Zender et al., 2019). The study of the Virtual Human Interaction Lab of Stanford University investigates the effect of embodying animals in VR in increasing inclusion of nature in self and demonstrates the potential of the embodied experience of interconnection with other animals to be an effective method for environmental issues by changing the behavior outside VR (cf. Ahn et al., 2016; Bucher, 2018). The study by Kontra et al. (2015) compared the passive and active learning in Physics and indicated that the physical experience in science education involving kinetics could enhance students' ability to account for the vector nature of angular momentum. They raised a model to explain how the physical experience could attribute to the understanding of angular momentum. The physical action experience activates sensorimotor brain systems, which, in turn, enhances the understanding of the knowledge (cf. Kontra et al., 2015).

This section discusses the implication of the learning theory of behaviorism, cognitivism, constructivism, and embodied cognition on the design, development, and evaluation of the virtual reality training and learning experience. Behaviorism sheds light on the interactive components in the VR environment based on the stimulus-response mechanism and leads to the implementation of gamification. Certainly, cognitivism development indicates the importance of intrinsic motivation. In the virtual learning application, the constructivism theory is mostly applied with the theory of the zone of the proximal development, the principle of situated learning, the concept of cognitive apprenticeship, the method of anchored instruction, and other implemented approaches. The didactical approach of embodied cognition is more applied in the virtual reality environment, with more interactive and immersive possibilities than in the traditional media didactical design, having a great influence on the user experience and learning outcomes in the VR learning scenarios. The technology of virtual reality is a way of expansion of the possibilities of simulation of authentic situations and complex problems with software and hardware (cf. Reinmann et al., 1994). The design, development, and implementation of the virtual reality training and learning environment should base on the existed learning theories and extend the further training and learning possibilities in practice.

4.2. Learning motivation in VR

Scholars have raised various questions in the field of learning in a mixed reality system. Though the mixed reality system could support constructivist vocational education in many ways, there is still a lack of research that addresses the issue of “How each of the features of the mixed reality system enhances learning outcomes or learning understandings” rather than “Does the mixed reality system enhance learning outcomes” (cf. Lee et al., 2010; cf. Salzman, Dede, & Loftin, 1999).

From the pedagogical perspective, various elements influence the learning outcomes, such as teaching plan, teaching strategy, and teaching environment. From the perspective of students, there are learning methods, learning tools, and learning purposes that affect learning motivation. In both empirical research or theoretical research on the learning achievement of students, learning motivation is considered one of the critical factors, which has continued existence and lasting influence on learners (cf. Prenzel, 2014). Therefore, the section following will discuss the definition and the dimensions of the learning motivation of students in the virtual reality system.

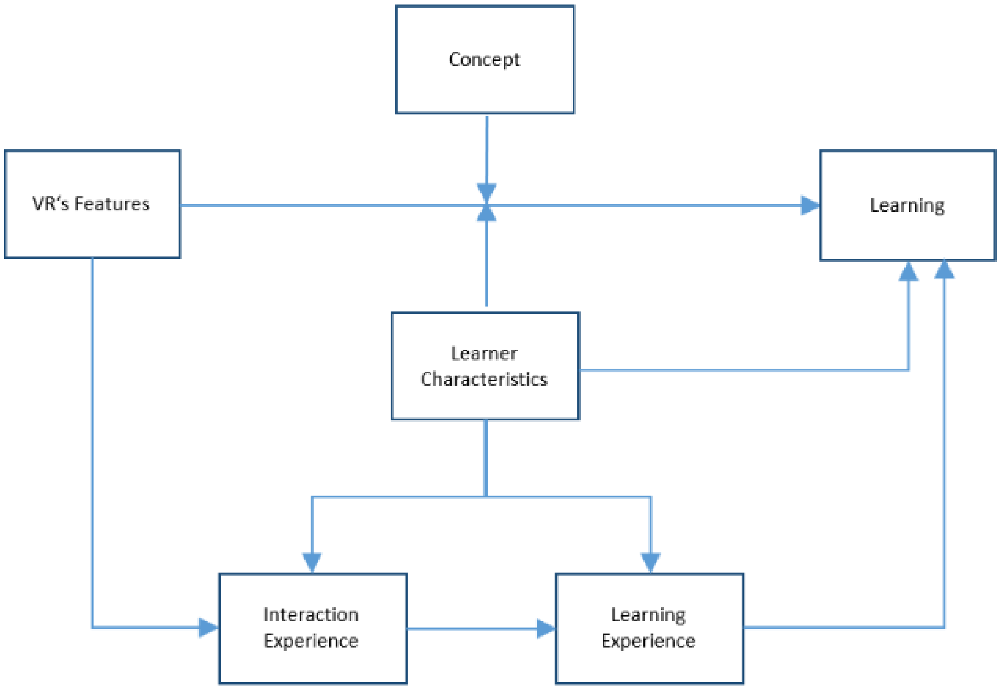

Figure 4-1 A general model by Salzman, Dede, Loftin, and Chen (1999)

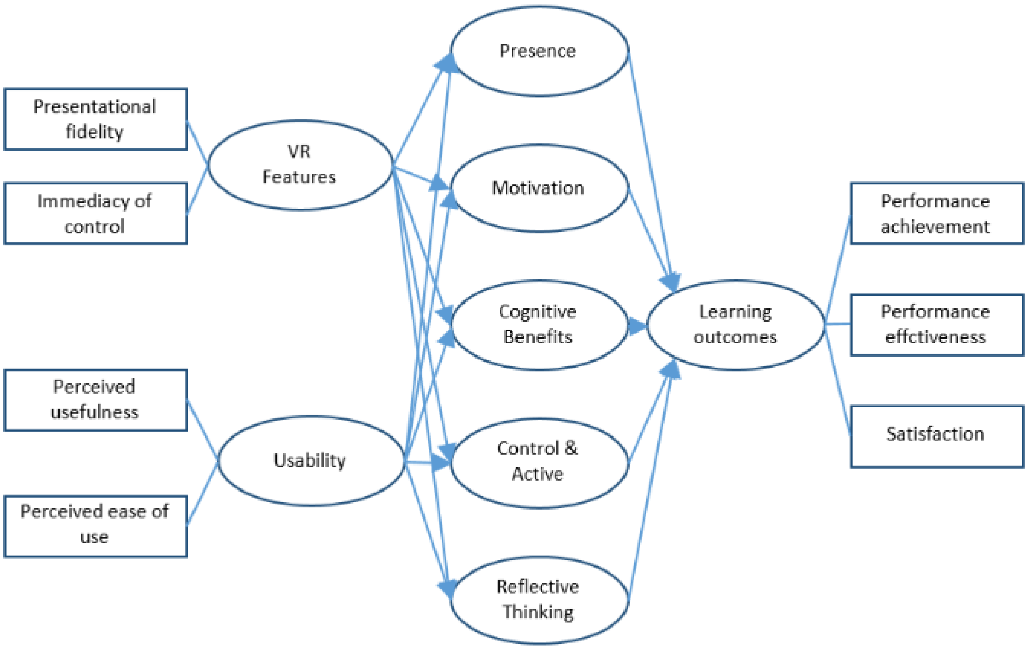

Figure 4-2 Research model by Lee et al. (2010)

4.2.1. Definition of learning motivation

Motivation has always been a core topic in the field of educational psychology, concerning all the aspects of activation and intention of behaviors of a human being. Generally, motivation is defined as "a psychological process with an active orientation of the current execution of life towards a positively evaluated target state" (cf. Rheinberg, 2006). The motivation of an individual to pursue a particular goal depends on situational incentives, personal preferences, and interactions. The motivation tendency consists of the incentives for the activities, the outcome of the action, and the internal self-evaluation-related and the external consequences, weighted according to the personal motivational profiles (cf. Heckhausen & Heckhausen, 2006). Motivation is not a subjective experience or behavior that can be described precisely, but an abstract concept that can be influenced by various processes, behaviors, or emotions (cf. Dresel & Lämmle, 2017).

Motivation has a close relationship to personal traits, like curiosity, social requirements, and other instinctive traits. The behavior under the basic conditioned reflex shows the motivation of specific behaviors. However, for some behaviors, the stimulation of behavior occurs in the specific behavior process instead of the anticipated results of the behavior, which is referred to as intrinsic motivation by many researchers and is relevant to self-satisfaction (cf. Brunstein, 2006; cf. Rheinberg, 2006).

An influential model of the modern understanding of motivation would be the Rubicon model of action phases, which makes distinctions between motivational and volitional processes as well as between the initiation and conclusion of action (Figure 4-3).

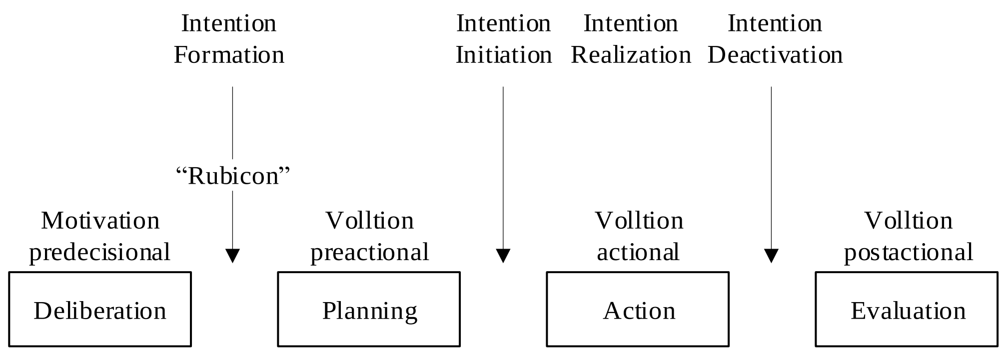

Figure 4-3 The Rubicon model of action phases (cf. Achtziger & Gollwitzer, 2006; cf. Heckhausen & Gollwitzer, 1987)

In the predecisional phase, the individuals deliberate how meaningful it is to achieve the goal they choose, weigh the feasibility and desirability of the wishes. The individual translates the goal into action, by committing to the goal and crossing the "Rubicon". In the preactional phase, the individual contemplates how to realize the goal, make the plan and find the strategies. In the action phase, the individual realizes the goal with the formulated plan and regulation of efforts. In the postactional phase, individuals evaluate the outcome of the successful or unsuccessful action, which affects the future actions by increasing or decreasing the motivation and aspirations (cf. Achtziger & Gollwitzer, 2006; cf. Heckhausen & Gollwitzer, 1987).

In terms of the influential factors of motivation, researchers added the process of self-regulatory feedback into the traditional motivation model and emphasized the function of situations. In daily learning life, there is more than one type of important expectancy and incentive because of the different positive evaluations of the consequences.

To explain the daily learning motivation, the simple traditional model was expanded by Heckhausen and Rheinberg (1980) and modified by Rheinberg (2006). As in Figure 4-4 presented, the motivation of an individual is affected by both personal characteristics and the situation.

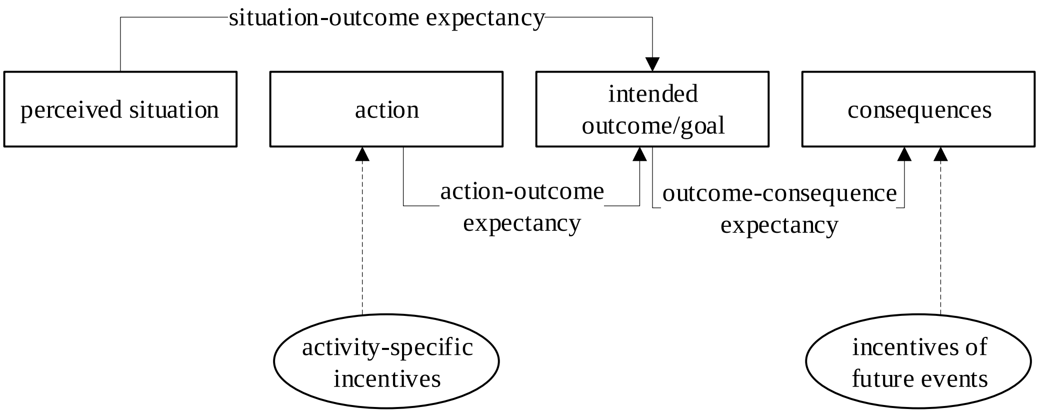

Figure 4-4 Expanded motivation model (cf. Heckhausen & Rheinberg, 1980; cf. Rheinberg, 2006)

The perceived situation, the possible action, the intended outcome or goal of the action as well as the consequences of the result build up the four components of the model. This theory model assumes that the motivation to be more likely when the situation - outcome expectancy is low and the action-outcome expectancy is high. Additionally, the activity-specific incentives and the incentives of future events, meaning that how vital the action to the individual is now and in the future, are both positive factors of the motivation. The two types of incentives could be combined into one activity. The activity-specific incentives include the activities that one engages without extra stimulus, by which the flow-experience would be encountered (cf. Heckhausen & Rheinberg, 1980; cf. Rheinberg, 2006).

Learning motivation is the motivation towards learning activities. The quality and the intensity of the motivation towards learning influence the quality of the consequences of the behaviors. The main results of the learning and achievement motivation include the initiation of action for learning and achievement, the adequate placement of plans and subgoals, persistence for learning, reasonable self-regulation, less irrelevant cognition, learning growth, and high achievement quality (cf. Dresel & Lämmle, 2017; cf. Frenzel & Stephens, 2017).

4.2.2. Components of learning motivation

Although motivation is sometimes treated as a single construct, it has various factors and sub-constructs due to the experience and emotions of individuals. In terms of learning, a student may finish the homework because of his satisfaction when finishing the homework or his avoidance of punishment when not finishing it.

Students may engage in the physic experiment due to their interest or the high scores from the teachers. People can be motivated due to their internal value, interest, endorsement, volition, and choice, or external seduced coerced or pressured impacts on themselves, which forms one of the basic categories of motivation, autonomous motivation and controlled motivation, namely, intrinsic motivation and extrinsic motivation (cf. Deci & Ryan, 2004; cf. Ryan & Deci, 2000b).

Based on three kinds of needs of human beings: competence, relatedness, and autonomy, the self-determination theory (SDT) argues that motivation can be divided into three categories, amotivation, intrinsic motivation, and extrinsic motivation (cf. Ryan & Deci, 2017). To a detailed degree, they proposed a spectrum of motivation based on the regulatory styles of behaviors ranging from non-self-determined to self-determined behavior as in the following graphic.

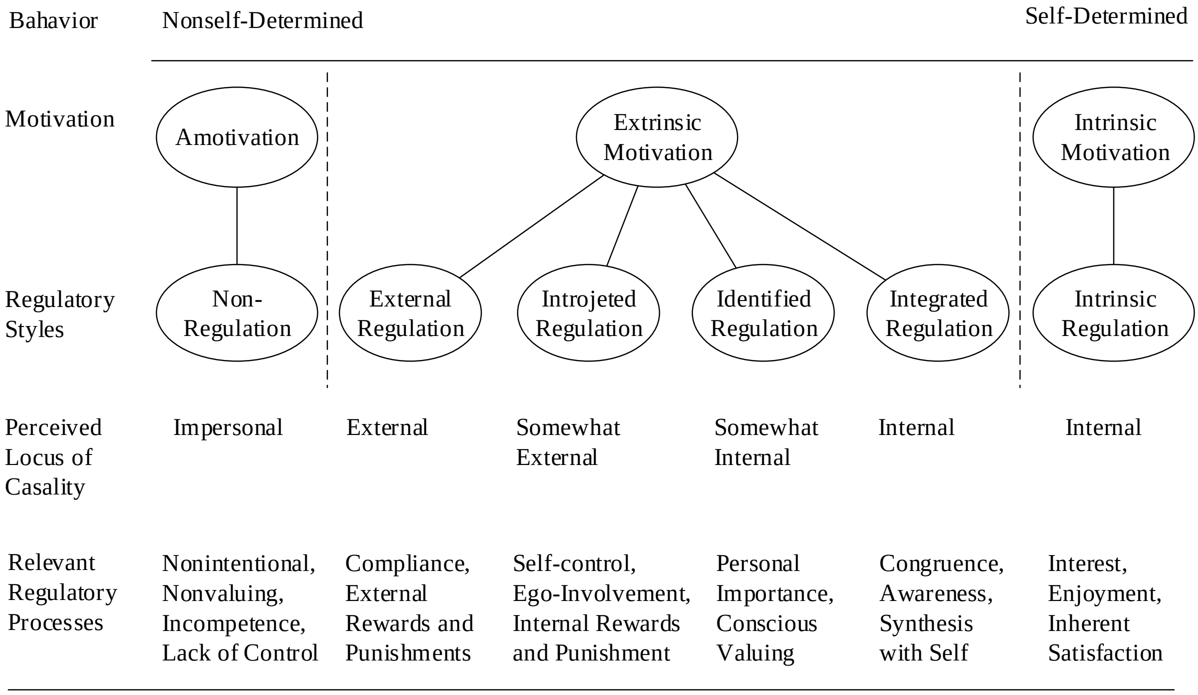

Figure 4-5 The self-determination continuum showing types of motivation with their regulatory styles, loci of causality, and corresponding processes (cf. Deci & Ryan, 1993; Ryan & Deci, 2017)

Based on the theory of self-determination theory (cf. Deci & Ryan, 1993) and the pedagogical interest theory (cf. Krapp, 1999; cf. Prenzel et al., 1986), Prenzel et al. (1996) proposed six variables of learning motivation, including amotivated motivation, external motivation, introjected motivation, identified motivation, intrinsic motivation and interested motivation (cf. Prenzel et al., 1996).

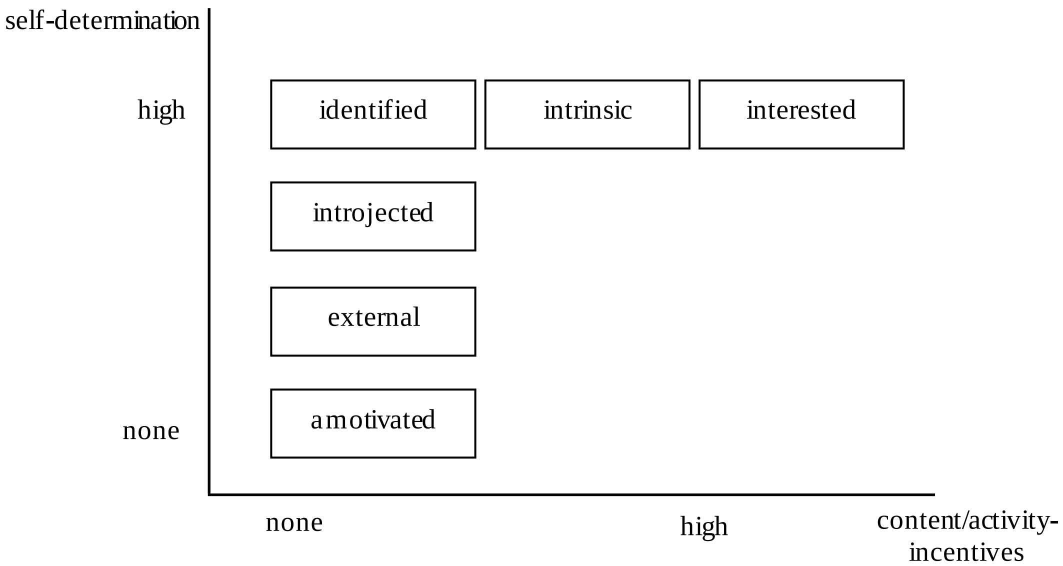

Figure 4-6 Six variants of learning motivation (cf. Prenzel et al., 1996)

In the self-determination theory, the distinction between intrinsic and extrinsic motivation is indicated. Intrinsic motivation refers to "doing something because it is inherently interesting or enjoyable", and extrinsic motivation refers to "doing something because it leads to a separable outcome" (cf. Ryan & Deci, 2000a). The learning experience could be different from the behavioral reason for intrinsic or extrinsic motivation. Intrinsic motivation could lead to a high-quality learning experience, which is a critical element in education. Extrinsic motivation could rely on external benefits or punishments. However, some of the extrinsic motivation can be performed with an attitude of willingness, such as an inner acceptance of the value of a task or the further utility, which is indicated in self-determination theory (cf. Ryan & Deci, 2000a). From a process-oriented view of intrinsic and extrinsic motivation, an activity can start due to extrinsic motivation but then continue due to intrinsic incentives (cf. Rheinberg, 2006).

This section describes the development of the research on learning motivation and the components of virtual reality environments. One of the principal research focuses is the relationship between learning motivation and other learning factors in virtual reality with natural user interfaces and the influences of learning motivation on the learning process as well as user experience. Klingauf et al. (2019) conducted a study of a classical handicraft task with students in vocational education. The study results indicate that learners have more motivation and distraction in the immersive virtual environment than with traditional desktop videos. Although motivation and distraction have no significant correlation with the learning results, they have a significant correlation with subjective learning results, which are subjectively evaluated by the participants. Whether the real learning results will be affected is still to be studied.

4.3. Didactical design in VR

This project of learning in a digital learning environment focuses on a new learning form, under the concept of the paradigm shift of "shift from teaching to learning" (cf. Barr & Tagg, 1995; cf. Richter, 2005). From the perspectives of learning instruments and platforms, the following sections discuss the learning patterns based on the above-mentioned learning theories.

4.3.1. Learning in computer-mediated environments

Köhler et al. (2008) summarized the concepts of "media" and "multimedia". "Media" is the means of interpersonal communication and information transmission, colloquially connected with newspapers, magazines, radio, and television, offering cooperative activities for knowledge transfer as well as transmitting pictures, sounds, and texts (cf. Köhler et al., 2008, p. 479). Specifically, in terms of teaching and learning, media mainly means the technical equipment and configurations as the tools of communication or data storage (cf. Köhler et al., 2008, p. 479). "Multimedia" involves the integration and parallelism of various media forms, such as time-dependent and time-independent media, as well as interactivity with the media (cf. Issing & Klimsa, 2002, p. 559). From the didactic aspect, learning with new media differs from learning with the traditional media, with respect to the main character of interactions, including interpersonal interactions or person-object interactions. As with teaching and learning in traditional media, the utilization of new mediated technology should consider the content and context of teaching and learning (cf. Köhler et al., 2008, p. 479). The diversity of applications offers a permanent availability of learning materials and learning interfaces, enhancing the efficiency of teaching and learning processes and replacing some parts of conventional teaching methods.

When using new media and multimedia in the context of learning, E-learning was proposed and has been widely used in both academic and non-academic fields, especially on sorts of media platforms in colleges and universities, such as the Open University[38], the Open University of Hong Kong and the Network Education College[39], Open Universities Australia[40] and Beijing Open University[41]. According to the findings of the research results within a holistic model for the evaluation of online remote laboratories in manufacturing technology education, the usage of remote lab increases the students' level of proficiency, based on the students' self-assessment and pre-evaluation and post-evaluation approaches (cf. May et al., 2016).

As our information flows online, we create a new world for ourselves, which provides a unique environment with connections and interactions (cf. Kelly, 2017). The form of E-learning is

[38] More information about the Open University: http://www.open.ac.uk/

[39] More information about the Network Education College: http://www.cmr.com.cn/

[40] More information about the Open Universities Australia: https://www.open.edu.au/

[41] More information about the Beijing Open University: http://www.btvu.org/enbtvu/index.html

changing dramatically with the changing context of information technology, from the form of software, and website, to further edging technologies like virtual reality, with not only the local installed software and hardware but also the connected worldwide web on browsers, computers, or mobile phones. So E-learning is an umbrella term for learning contexts by means of information technology. Additionally, the main basic goal of E-learning is not changing, which is to support or improve the quality of communication, expression, and comprehension in teaching and learning (cf. Reinmann-Rothmeier et al., 2003).

Reinmann-Rothmeier et al. (2003, p. 33) divided E-learning into three kinds based on the main functions of media and their effects on learning, which are the distribution of information, the interaction between learners and systems, as well as the collaboration of learners. The distribution function of E-learning is based on the massive storage of the internet and the fast searching technology, which is useful for the situation of getting electronic information from the internet, self-processing, self-controlling and self-application when the functions of teachers are not required. Interactive E-learning is the learning form when the goal of learners is getting feedback, offering the interaction between users and the system, and, for example, timely evaluations to continue the learning content (language learning software or tutorial software). The project PeTEX (Platform for Telemetric Experimentation) in mechanical engineering consists of the design-based research (DBR) of E-learning, connecting the virtual and real experiment environment and realizing high learning motivations of students in further education (Jahnke, 2016, pp. 177–200). E-learning by collaborating is developed to increase the amount of E-learners, typically integrated into online seminars with learners working on homework in groups without limits of time and location, where the functions of teachers are indispensable. It encourages learners to construct new knowledge structures, exchange experiences, and solve problems together in the virtual space collaboratively (cf. Reinmann-Rothmeier et al., 2003), such as the collaborative learning software Construct3D by Kaufmann et al. (2000).

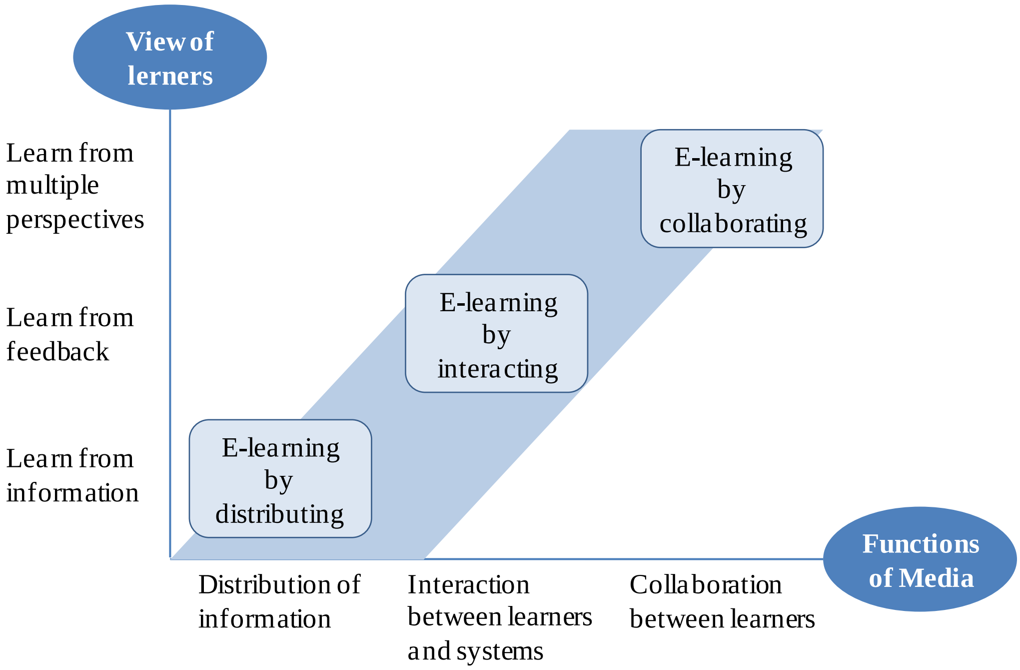

Figure 4-7 Varieties of E-learning (cf. Reinmann-Rothmeier et al., 2003, p. 33)

The higher the level of E-learning, the more complicated and integrated it is. The more complicated the system is, the more demanding it is on the competence of learners, including media-controlling competence, self-controlling competence as well as social competence. The various learning forms should meet the various requirements from both the aspect of learners and the aspect of learning processes (cf. Reinmann-Rothmeier et al., 2003).

4.3.2. Learning software

The self-controlling character of learning with software is the main feature of the development of learning content, learning progresses, learning environment, as well as synchronous or asynchronous communication methods, from the perspective of constructivism (cf. Kerres, 2012, p. 454). To realize the required functions of the learning environment, technical functions are significant nowadays. Based on the technical functions and software characters, Baumgartner and Payr (1999) summarized the learning software types as well as the concerned didactic concepts as follows (cf. Baumgartner & Payr, 1999; Köhler et al., 2008).

Table 4-1 Learning software types (cf. Köhler et al., 2008, p. 481)

Software type	Function	Media didactic concept
Visualization	Reminding and receiving	Learning centering
Drill and Test	Establishing and practicing	Task orientation (module)
Tutorial	Choosing	Task orientation (system)
Intelligent tutorial	Modeling of strategies	Task and act orientation
Simulation	Discovering of relations	Discovery and act orientation
Hypermedia	Designing	Discovery and act orientation

Visualization is mainly about the expression and statement of different documents on screen, especially for the conveying of factual knowledge (e.g., Microsoft PowerPoint, Keynote of Apple, Prezi, and Google Docs). A significant advantage of the virtual reality learning environment would be the various possibilities of visualization of the relationships and objects, delivering the information with simulation, illustration, and interaction in a 3D-world (cf. Münzer, 2012, 2015).

Drill and Test (also known as “drill and kill” or “teaching to the test”) methods are used for the systematic practice presented with the heavy and tight focus of preparing a test (e.g., vocabulary training). The tutorial system gives the learners a series of knowledge sets and understanding tests for the purpose of handling harder knowledge (e.g., The Python Tutorial, The Java™ Tutorials).

The intelligent tutorial system is a further developed version of the regular tutorial, which adapts itself to the learning process of learners. The self-learning of the intelligent tutorial system is automatic, named as the technology of artificial intelligence (AI). For example, in some learning games, the difficulty and complexity of the problems offered to the learners change depending on the current performance of the learners. The adaptive communication between the learners and the system builds the training process for the intelligent system for the optimization of feedback.

Simulation and hypermedia are widely used with immense interest in the field of entertainment, involving users constructing a simulated world, exchanging complex information, and developing themselves individually in this environment (e.g., SimCity, the Sims, and Virtual

Life) (cf. Baumgartner & Payr, 1998; cf. Köhler et al., 2008, p. 481). In the VR learning environment, simulation is one of the key features for presenting knowledge. Scenarios of simulation in VR are introduced in detail in Chapter 2.

Since the early 2000s, the term blended learning has been often used to describe a variety of academic and educational techniques, including MOOCs and the flipped classroom. The Association for Talent Development emphasized the importance of blended learning in the field of knowledge delivery (cf. Hofmann, 2018). Blended learning refers to a system that combines traditional knowledge-based and distributed technology-based learning, with a focus on computer-/web-based technologies (cf. Graham, 2006). The prosperity of blended learning brings more requirements in terms of the technical aspects, encouraging the development of additional trials in the execution of different functions in teaching and learning (cf. Fredebeul, 2012).

In terms of virtual reality, the various possibilities of this technology make it possible for the virtual reality learning program to have more than one didactical method at the same time. Therefore, how to build a functional and practical virtual reality learning application and deliver the learning content based on the existing media didactics is a question to go after.

This section illustrates the learning design in computer-mediated environments with various technological characters as well as the various learning software with the corresponding integrated media didactical concepts. The use of virtual reality technology for creating training and learning environments holds great promise, and there are already many experimental and applied practices. One of the preconditions for the design of a learning VR application would be the pedagogical foundation. The design of learning in VR, like the other learning designing processes of the user experience illustrated in Chapter 3, needs systematic phases including requirement analysis, concept design, development, and evaluation.

4.4. Interim conclusion to learning in virtual reality

This chapter gives an illustration of the applicable learning theories in training and learning in VR environments firstly. All the theories of behaviorism, cognitivism, and constructivism have various implications for the design and development of the learning experience in VR. Although some of the outdated learning theories are not suitable for VR learning practice, many theories and principles are of great significance.

From the perspective of the inner influential aspects of the learning activities in VR, the literature research on learning motivation is conducted in this chapter, as well as the practical cases in VR. The immersive and interactive VR environment gives possibilities to enhance the learning motivation of the learners and therefore improve the learning experience and learning outcomes. Therefore, learning motivation is examined in the empirical experiments in Study I and Study II.

From the didactical design with traditional computer-mediated learning environments, the various categories of learning software and corresponding didactical approaches are analyzed. The specific characteristics of VR, such as the immersive, simulated, and interactive features, bring the theory of embodied cognition into focus, which explains the relationship between the learners in VR and the environments.

Although there are a number of VR learning applications, which could record the learning data, there is still little research about the user experience in the learning scenarios with the concrete learning sessions in vocational education. The theoretical research in this chapter, together with the description of the VR technology as well as the illustration of the user experience in Chapter 2 and Chapter 3, builds the theoretical foundation of the further empirical studies of the training and learning scenarios in Study I and Study II.

5. Research Questions and the Conception of the Empirical Studies

5.1. Research questions and hypotheses

This research presented focuses on the generation of a descriptive knowledge of user experience of virtual reality technology in the context of training and learning in virtual environments. The hypothetical model of Salzman, Dede, Loftin, and Chen (1999) describes how VR features, learner characteristics, the concept of learning, the interaction experience, and the learning experience influence the learning process and learning outcome in a VR learning environment. In the context of teaching and learning with a VR-based learning environment, Lee et al. (2010) stressed the input, mediating, moderating, and output processes. They compared the immersive VR theoretical model of Salzman, Dede, Loftin, and Chen (1999) and other technology-mediated models (cf. Benbunan-Fich & Hiltz, 2003), summarized the relevant dimensions of VR-based learning, and developed a research model for evaluating the VR learning environment with the technical constructs and the psychological constructs of VR features, usability, presence, motivation, cognitive benefits, control and active, reflective thinking and learning outcomes. In line with some other studies (cf. Benbunan-Fich & Hiltz, 2003; cf. Salzman, Dede, Loftin, & Chen, 1999), the presence, motivation, and usability were found to be significantly and positively related to learning outcomes in the VR-based learning environment (cf. Lee et al., 2010). The conceptual framework of Fowler (2015) in designing the learning system indicates that immersion in the VR system is a key component from the psychological and pedagogical perspectives.

Based on the conceptual framework and research models with mediated technology as well as VR technology, a research model is developed for describing and evaluating the relevant constructs in both traditional and immersive virtual reality environments. In this research, the observed dimensions in the teaching and learning scenarios are presence, usability, learning motivation, as well as the flow experience of the participants of the studies. It is also meaningful to investigate the relationship between the observed dimensions as well as the influential relationship between them in both VR scenarios.

Studies show that the flow component is a central construct in the user experience and indicates the significant influence of presence on the flow experience through the path analysis in their studies (Schuster et al., 2014; Schuster et al., 2017; Sherry, 2004; cf. Voiskounsky et al., 2004;

cf. Weibel & Wissmath, 2011). Therefore, it is expected that the spatial presence has an influence on the flow experience of the participants in virtual reality (Hypothesis 4).

The study of Weibel and Wissmath (2011) indicates that motivation also has an influence on the flow experience of the individuals. Engeser et al. (2005) also suggested that motivation is an influential component in building the flow experience. Thus, we expect that motivation has a positive influence on the flow experience in the learning and training scenarios (Hypothesis 6).

The study of Pilke (2004) indicates that good usability leads to the flow experience and the flow model is suitable for examining the quality of the user experience. The theoretical framework of Kiili (2005) also suggests that the bad usability in game-based learning would decrease the likelihood of a flow experience in computer-mediated environments because the participants would have to sacrifice their cognitive resources for the activities with usability problems. Thus, the expectation in this research is that usability has an influence on the flow experience (Hypothesis 5).

The results of the studies of (cf. Lee et al., 2010, p. 1431) with desktop-VR learning software show the positive correlation between usability, presence, the motivation of the participants. Therefore, the perceived usability of the application should be positively related to the spatial presence (Hypothesis 1). The correlation between presence and motivation is also suggested in the studies of Weibel and Wissmath (2011), which leads to the hypothesis that spatial presence is positively correlated to learning motivation (Hypothesis 2). Besides the frameworks of the mentioned studies indicating the relationship between usability and motivation, Hu (2017) also indicates the correlation between motivation and usability in a digital learning environment, which leads to the expectation in this research that the perceived usability of the application is positively related to the learning motivation of the individuals (Hypothesis 3).

Table 5-1 the hypothesized relationships in the model (source: own presentation)

Hypotheses	Justification of the hypotheses
H1: Spatial presence is significantly positively correlated to usability.	Lee et al. (2010)
H2: Spatial presence is significantly positively related to motivation.	Weibel and Wissmath (2011)
H3: Usability is significantly positively related to motivation.	Hu (2017)
H4: Spatial presence has a significant positive influence to flow.	Schuster et al. (2017); Schuster et al. (2014); Sherry (2004); Voiskounsky et al. (2004); Weibel and Wissmath (2011)
H5: Usability has a significant positive influence on flow.	Pilke (2004); Kiili (2005)
H6: Motivation has a significant positive influence on flow.	Weibel and Wissmath (2011); Engeser et al. (2005)

The following figure shows the hypothesized relationships in the model.

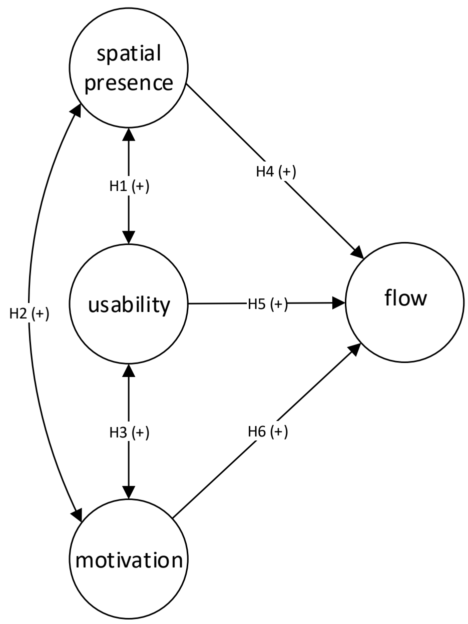

Figure 5-1 The research model of the studies (source: own presentation)

To validate the expectations, two studies in different learning contexts were conducted. One study is conducted with the desktop-based virtual reality technology with the learning and training content of social competence (Study I). Another study investigates the hypotheses about the immersive version of virtual reality with the hardware Oculus Go in the field of physical sensor teaching and learning (Study II).

5.2. Overview of the design of empirical studies

Based on the practical experience and the literature research of the VR-technology for learning in Chapter 2, the dimensions of user experience for learning in VR in Chapter 3, and the learning theories in Chapter 4, the empirical studies of this research in Chapter 6 and Chapter 7 focus on the description and evaluation of the training and learning application scenarios of a virtual learning and working environment (VILA) with a traditional virtual reality interface for the training of social competence (Chapter 6) and a virtual physical sensor laboratory (VPSL) with an immersive virtual reality interface for the learning of physical sensor knowledge (Chapter 7).

The implementation of the technology of virtual reality has been not so long in vocational education, and the development of the technology itself is still in the preliminary research phase with various hardware and software. Therefore, the examination of different technology in the context of different training and learning scenarios in vocational education would be of great importance. Desktop-based VR technology and immersive VR technology would be the most popular approaches in the training and learning field, considering the scale of the learning population. The technology of CAVE and other representations that are popular in the industrial and marketing fields are not suitable for large-scale training and learning from the efficiency and economic perspective. It requires more proficiency and professional knowledge of the technology to be implemented. Therefore, the studies in this research are conducted with desktop-based VR technology for Study I and a customer version of an immersive VR technology for Study II.

In Study I, the VR environment is a collaborative software platform (VILA) with a 3D representation of a building with different kinds of spatial functions and some interactive functions, such as navigation with keyboard and mouse, presentation with a virtual wall projector, and communication within the group with the microphone and earphones in the headset. Each participant is facilitated with a laptop or computer with a keyboard, a mouse, and a headset. The training content would be social competence, specifically perspective-taking (in German: Perspektivenübernahme). The didactical design of the training session is adapted from a training session of a project that was validated as an effective design. Two groups of participants are in Study I. The group of students in the major of vocational education in the university (n = 72), who are the potential teachers in the vocational schools after graduation, and the group of the students in vocational education (n = 62). The details of the environmental setups, the training content, the training procedures, and the methodology of Study I are presented in Chapter 6.

In Study II, the training and learning are conducted with an immersive application of a physical sensor laboratory (VPSL), with the immersive simulation of various physical sensor experiments, the interaction with the objects in the virtual laboratory, as well as the virtual visualization of the conveyed knowledge. The virtual physical laboratory is compatible with a VR headset with an already integrated monitor, processor, speaker, and rotation sensors. The interactive controller with rotation sensors facilitates interaction with the objects in the virtual environment. The learning and conducting of five sensor experiments are designed in the VPSL. Several vocational schools are willing to explore the possibilities of VR teaching and learning in the field of mechanical and technical engineering. Every study session is conducted within a classroom for collaborative design and in groups to secure the participants. The details of the experimental setups, learning content of the physical sensors, learning procedures, and the methodology of Study II are presented in Chapter 7.

Study I and Study II are proposed to gain insight into the user experience design principles and decisions for the improvement of the future application of VR technology in the training and learning areas. Based on the results of the formative evaluation of the designed empirical studies, this thesis focuses on the improvement of the VR training and learning applications towards a high-quality and completed application and the enhancement of the underlying user experience design principles towards a set of applicable and comprehensive design principles.

6. Study I: An Empirical Study with Virtual Reality with Traditional Interface[42]

This chapter presents a study that focuses on the explanation and description of the implementation of a virtual reality learning and working environment (VILA) as the application for the training of the competence of perspective taking in the field of social competencies. To meet the requirements of the virtual learning environment for the technical service industry, a systematic analysis was conducted with the relevant constructs of spatial presence, flow experience, usability, learning motivation, professional interest, and the general participant characters. The following are the study design, the study result, and the discussion after the study.

6.1. Research background

In recent years, companies in mechanical and plant engineering are facing various challenges of personal recruitment and development, which require the application of new and dynamic technology. Regarding the importance of economic effectiveness and efficiencies, the personal development of the decentralized individuals needs to be conducted with virtual technology, considering the time and cost of on-site training and learning (cf. Zinn, 2017).

Platforms such as online, mobile, or virtual reality could be helpful for knowledge transfer and skill training. With the rapid development of virtual reality technology, an immersive and interactive online training learning scenario is now possible with an advanced user interface with simultaneous visualization and interaction.

In order to meet the specific requirements of the virtual learning environment, it is significant to get a systematic analysis of the learning environment about usability, presence, flow under the control of motivation, interest (e.g., studying interest), and general learning features (e.g., age, computer experience). A conceptual framework of the research and the hypotheses of the study of virtual learning are in Chapter 5, including the constructs and their relationships, and

[42] Parts of the experimental design and empirical results in this chapter were published in the article of Zinn, Guo, and Sari (2016).

focuses on the research on the influence of the VR environment on learning motivation. The measurement factors are described in the following sections.

In this study, the evaluation of the training and learning platform VILA will be conducted based on the research background and hypotheses in the former chapters as well as on the learning conditions and learning content. The study focuses on the assessment of the constructs, which are usability, presence, learning motivation, as well as the flow of the students. Additionally, professional learning interests, computer usage, as well as personal traits, will also be presented.

6.2. Experimental design

6.2.1. Environmental setups

This study uses a new 3D learning and working platform[43] to develop the learning environment, which supports asynchronous self-learning as well as synchronous team learning, providing a new dimension for the learning and working environment where location-independent and time-independent learning and working activities are possible. The virtual space provides the same spatial functions as in an actual architectural space, including a foyer for receptions and introductions, an auditorium for presentations and lectures, two separate meeting rooms for discussions and group work. Most of the virtual rooms in the learning environment have the integrative possibilities of several media resources. For example, there are media walls to present documents, pictures, and videos, there are showing tables to present the constructions and animations of 3D models, and there are interactive whiteboards to show instant ideas. During the learning, all the participants can use these interactive media interfaces. The following picture shows the auditorium with two media walls, one showing a video vignette and the other showing a presentation document.

Individuals use avatars to represent themselves in the virtual environment, where they can freely move, speak with other participants, as well as edit or update the media resources of the media walls (e.g., together with writing documents, playing videos, showing graphics, or observing the animated 3D models). The appearances of avatars are chosen and decorated (e.g., clothes

[43] The technical environment is developed by the company TriCAT (Ulm) and applied in this study for research purposes.

and hair) individually by the participants before they get onto the platform.

Figure 6-1 A scene of a presentation with avatars (A teacher and four training participants) in the auditorium (source: own presentation)[44]

The participants use headsets with microphones and headphones, keyboards, and mice to navigate the movements, gestures, and communications of their avatars. The field of view is controlled by a mouse. The locomotion is controlled by WASD-keys or arrow-keys to move forward, backward, left, and right on the keyboard.

6.2.2. Training content

In terms of vocational education for the competence of employees in the mechanic and plant engineering fields and the project of EPO-KAD (Abbreviation in German: Erschließung des Potenzials älterer Mitarbeiter durch lebensphasenorientiertes Kompetenzmanagement und Arbeitsprozess-gestaltung in industriellen Dienstleistungsprozessen; English: Development of the Potential of Older Employees through life-phase-oriented Competence Management and Work Process Design in Industrial Service Processes), a technology-didactic knowledge transfer concept (ServiceLernLab) was designed and conducted in the praxis, with the center

[44] A screenshot of the learning scenario of VILA in the application of TriCAT Space.

elements of training for technical professional competences (cf. Zinn et al., 2015) and training for social competences (cf. Güzel et al., 2016), including the competence of perspective talking. The concept includes the modules of real model praxis, simulation, professional knowledge, professional skills, expert modules, social competence, and virtual learning (cf. Güzel et al., 2016; cf. Zinn et al., 2015).

The learning content focuses on perspective taking (in German: Perspecktivenübernahme), which is in the center of the social competence for the working field of industrial service technicians (Güzel et al., 2016; Mischo, 2004; Zinn, 2014; cf. Zinn, Guo, & Sari, 2016). Additionally, it is clear that the user interfaces, as well as their functions and technologies, should serve the learning content firstly. In this study, it only makes sense when the learning content is appropriate to the virtual environment. Therefore, considering the collaborative, flexible, gamified, and immersive features of the environment, the learning content exemplarily focuses on the aspect of the competence of perspective taking.

6.2.3. Training procedures

The participants are separated into several groups, and each group has the same training procedures controlled by the same training leader. In the training process, each participant sits in front of a computer or a laptop with a headset and a mouse. The participants in the same session were separated into different rooms to minimize the noise of other students. The whole training session lasts about 45 minutes to 60 minutes, followed by the evaluation of the training (Figure 6-2).

The five-minute introduction in the foyer of the virtual building at the beginning of the training provides a brief overview of the infrastructure of the virtual building, the basic functionalities of the virtual platform, as well as the navigation of the avatars (e.g., moving forward with keyboard, turning around and pointing with the mouse, and running with an added function-key).

Then the participants move to the auditorium, where the main training takes place. The main content begins with a presentation of the theoretical explanation with the topic of perspective overtaking in the field of social competence, including the description of the terms and the explanation of the different stages of perspective overtaking. During the presentation, the avatars that are representing the participants are either standing around or sitting on the benches in the auditorium, with the interactive functions of holding hands up, using facial expressions, and zooming in and zooming out the presentation for better visualization of the shown documents.

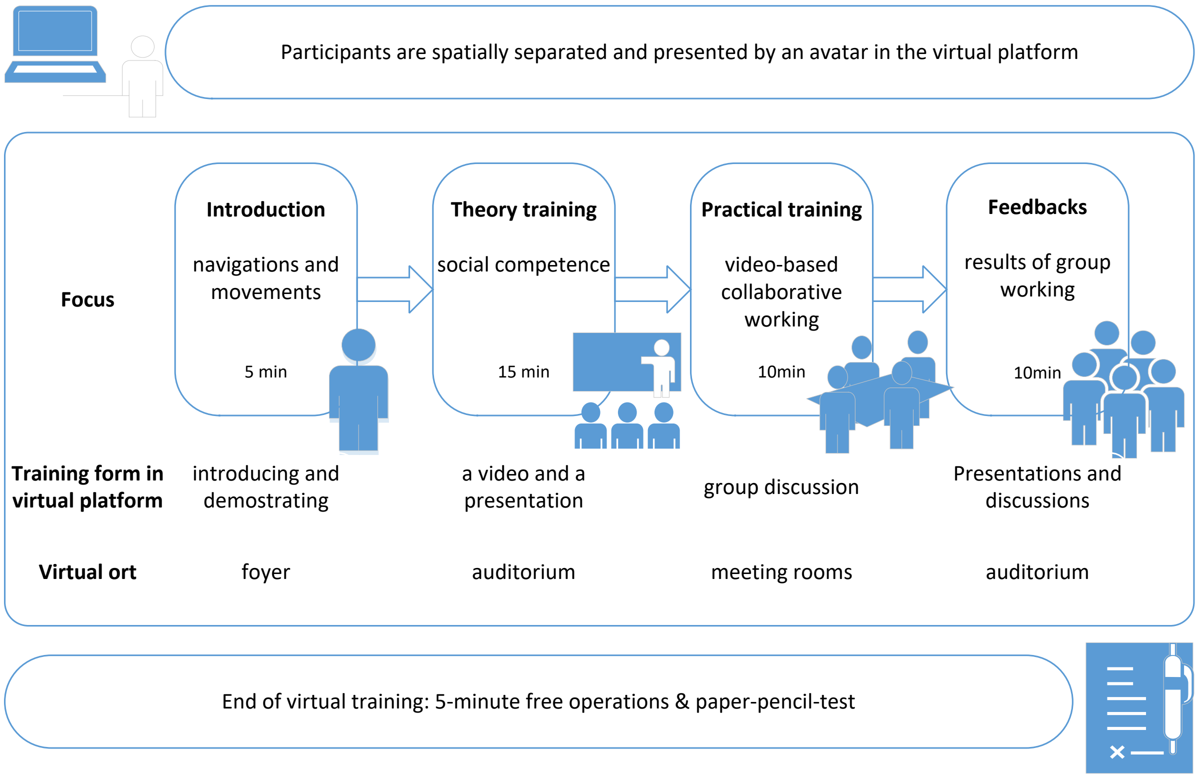

Figure 6-2 Training procedures of the study VILA (source: own presentation)

After the theoretical instruction orientation is the practical training phase with video case-based learning, showing the video vignettes with a media wall, in which a service technician in a dilemma case has to analyze the challenging task based on the available and existing condition under stress from external and internal demands in the typical context by communicating with the customer, analyzing the problem and offering solutions (cf. Güzel et al., 2016; Zinn, Nickolaus et al., 2016). The user case shown in the study was applied in the present training of the social competencies of the students in other studies (cf. Güzel et al., 2016). The learning (authentic) case in the video vignettes is an implementation of a real environment. In terms of the methodological and didactic concepts, case-based learning has been shown to be more beneficial than lectures classes in continuing education in studies. The authenticity and the repeatability of individual sequences make situated learning conductive (cf. Digel, 2010; cf. Goeze et al., 2010; cf. Goeze et al., 2013).

Then there is a writing group working based on the video case. As in reality, where participants are separated in different spaces, the avatars go to different rooms in groups where intragroup interaction and communication is possible, but intergroup communication is limited, which is realized because of the technical settings of the virtual environment, that the doors and walls between the meeting rooms cut off the transmitting of sound and image. After the group-working phase, the groups get together and present their discussion results in the conference room, and the trainer gives the thematic summary.

In order to give the participants a better impression and deeper knowledge of VILA, the last five minutes of the training are devoted to freely navigating in a virtual house, exploring more interactions, and experimenting with more specific features (e.g., changing the mimic and gestures). After the training with VILA, there is a questionnaire for the participants concerning the constructs of demographic data, spatial presence, flow, usability, professional interest as well as learning motivation.

6.2.4. Methodology

6.2.4.1. Participants

To evaluate the virtual learning environment from both the learning perspective and the teaching perspective, it is meaningful to conduct the study not only with the students in vocational education but also with the students in the majors of vocational education in higher education, who have the potential to be teachers in vocational schools after graduation. Therefore, there are two main groups of participants. A total of 134 students volunteered to participate in the study and learning sessions. Group 1 consists of 72 university students in vocational and technical education (26.4% male and 73.6% female) between the ages of 19 and 36 (M = 23.72; SD = 3.2), 43.1% of whom have completed their vocational education or have a degree; Group 2 includes 62 (future) service technicians (88.7% male and 11.3% female) in commercial and technical fields (mechanical technicians and electronic technicians) between the ages of 16 and 46 (M = 19.74; SD = 4.2) (Table 6-1). The study was carried out between December 2015 and April 2016.

Table 6-1 Demographic data of the participants (source: own presentation)

Participants	Group 1 College students (vocational and technical education)				Group 2 Students in vocational education (mechanical and electronic technicians)			
	n = 72				n = 62			
Gender	Male		Female		Male		Female	
	19 (26,4 %)		53 (73,6 %)		55 (88.7 %)		7 (11.3 %)	
Age	Mean	SD	Min	Max	Mean	SD	Min	Max
	23.72	3.2	19	36	19.74	4.2	16	46

6.2.4.2. Measurements

The measurement of spatial presence is the MEC Spatial Presence Questionnaire (cf. Vorderer et al., 2004; cf. Wirth & Hofer, 2008), which was developed in the context of an international project (Project Presence: Measurement, Effects, Conditions - MEC). The instrument is validated in several studies of the authors, where a validated two-level model explains the postulate of spatial presence, including process factors (attention allocation, spatial situation model, Spatial presence: self-location, Spatial presence: possible actions), variables referring to states and actions (higher cognitive involvement, suspension of disbelief) and variables addressing enduring personality factors (i.e., the trait-like constructs, domain specific interest, visual spatial imagery, and absorption[45]) (cf. Vorderer et al., 2004).

The instrument of spatial presence used in this study includes eight dimensions with a five-score rating scale (from 1 “disagree” to 5 “agree”: the higher is the score, the lower is the evaluation of the expression). According to Wirth et al. (2007), the scale of domain-specific interest indicates the specific interest that the participants experience in the learning process in the learning environment. The spatial situation model is the first level of the formation of the spatial presence as a precondition. The scale of the attention allocation is the devotion of mental capacity to the learning media. The persistence of attention allocation is also affected by the media. Higher cognitive involvement is regarded as a motivation-related concept that involves

[45] The evaluation of absorption is conducted with the instruments of flow of Rheinberg et al. (2013).

higher forms of information processing and interaction in the immersive mediated world than just "being in the world", such as thinking about, interpreting, elaborating, and other relevant processes. Visual-spatial imagery is one of the personological constructs of spatial ability that produces vivid visual imagery after being exposed to a media product, increasing the cognitive salience and supporting the formation of the spatial situation model. Self-location is the sensation of being physically situated within a unique environment, "being in the world". The dimension of possible actions refers to the perceived action possibilities and noticing the possible actions within the virtual learning environment (cf. Wirth et al., 2007). Suspension of disbelief refers to the extent to which one focuses on the technical and content-related inconsistencies (e.g., technical errors). Namely, the more one can ignore these inconsistencies in the virtual platform, the higher suspension of disbelief he has (cf. Wirth et al., 2008) (Table 6-2).

Table 6-2 The Cronbach's α of dimensions of spatial presence (source: own presentation)

Dimensions	Item number	Cronbach's α Group 1	Cronbach's α Group 2	Cronbach's α total
Domain specific interest	8	.888	.879	.883
Spatial situation model	8	.873	.836	.858
Higher cognitive involvement	8	.824	.865	.845
Attention allocation	8	.942	.921	.939
Visual spatial imagery	8	.835	.875	.854
Possible actions	8	.850	.887	.868
Self-location	8	.924	.939	.938
Suspension of disbelief	7	.712	.433	.632

Flow, as explained in this work, is the mental state of involvement and enjoyment in the process of the activity. The flow experience is measured with the Flow-Short-Scale (in German, Flow-Kurzskala; abbr.: FKS) of Rheinberg et al. (2003), including two subscales: fluency of performance and absorption (Table 6-3). The six items in the scale of fluency of performance interpret how the automatic regulation works. The four items in another dimension of the absorption include the items that explain the absorption through the activities. The reliabilities of the dimensions are shown in the following table.

Table 6-3 The Cronbach's α of dimensions of flow (source: own presentation)

Dimensions	Item number	Cronbach's α Group 1	Cronbach's α Group 2	Cronbach's α total
Fluency of performance	6	.834	.828	.832
Absorption	4	.702	.688	.711

To assess the usability of the virtual learning and working environment, an adaption of the usability questionnaire is used, which was developed EN ISO 9241-10 (cf. Europäisches Komitee für Normung, 1995) and the Isometrics (cf. Gediga et al., 1999) with six subscales, each of which has five items with a six-score scale (from "disagree" to "agree"). The instrument includes six dimensions of usability, which are suitability for the task, self-descriptiveness, controllability, anticipation conformity, customizability, and suitability for learning (Table 6-4), describing the dialogue principles for the user-friendly design. An interactive interface or system is suitable for the task when it supports the users in finishing the work effectively and efficiently and is in line with the users' expectations when it is consistent with the working field and the knowledge field of the users. The system is self-descriptive if the users can realize what to do and how to do it in the virtual learning environment. The users should have the ability to control the interaction with the interface or the system according to their wishes. The system is customizable when the system can adapt to the technical settings and context-related adjustments. Suitability for learning indicates the learning difficulties and the learning efficiency of how to use the interactive system (cf. Europäisches Komitee für Normung, 1995; cf. International Organization for Standardization, 2006).

Table 6-4 The Cronbach's α of dimensions of usability (source: own presentation)

Dimensions	Item number	Cronbach's α Group 1	Cronbach's α Group 2	Cronbach's α total
Suitability for the task	5	.797	.770	.783
Self-descriptiveness	5	.800	.762	.781
Controllability	5	.784	.827	.824
Anticipation conformity	5	.742	.849	.825
Customizability	5	.901	.806	.866
Suitability for learning	5	.785	.697	.747

The learning content concerns vocational training and working situations. The interest in the working or learning field is supposed to be considered when the experience in the virtual learning environment is evaluated (Table 6-5). The working and studying interest was surveyed with the "Study Interest Questionnaire" (SIQ) developed by Krapp et al. (1993). The feeling-related valence is referred to as the combination of activities and positive feelings (e.g., joy and pleasure). The component value-related valence indicates the connection between the activities and the appreciation from the perspective of personal significance. The feature of intrinsic character describes self-intentionality with reference to the combination of immanent feeling-related and value-related valences (cf. Krapp et al., 1993).

Table 6-5 The Cronbach's α of dimensions of vocational and study interest (source: own presentation)

Dimensions	Item number	Cronbach's α Group 1	Cronbach's α Group 2	Cronbach's α total
Intrinsic character	4	.588	.472	.496
Feeling-related valence	7	.752	.631	.696
Value-related valence	7	.828	.576	.743

The evaluation of the motivation of the participants is realized with the instrument adapted from the instrument of Prenzel et al. (1996), which has a six-score rating scale (from "never" to "very often") for perceived overloading, perceived competence, relevance attribution, intrinsic motivation and identified motivation (Table 6-6). The dimension of intrinsic motivation describes the learning states that exist solely to obtain external affirmation or to avoid punishment. The scale of the identified motivation indicates the motivated learning is considered to be of importance for goal attainment, despite the lack of appeal. Perceived overloading describes a learning state with more requirements than the learner can bear. Perceived competence includes the states associated with contextual feedback and knowledge acquisition. The scale of the relevance attribution indicates the connection of the learning content with its application in vocational learning and working (cf. Prenzel et al., 1996).

Table 6-6 The Cronbach's α of dimensions of motivation (source: own presentation)

Dimensions	Item number	Cronbach's α Group 1	Cronbach's α Group 2	Cronbach's α total
Perceived overloading	3	.686	.717	.699
Perceived competence	3	.699	.767	.741
Relevance attribution	3	.764	.832	.829
Intrinsic motivation	3	.877	.872	.896
Identified motivation	3	.774	.757	.792

Additionally, the sociodemographic data of the participants is collected and presented in the next section. The strength of flow and spatial presence experienced in the virtual environment is supposed to vary as a function of individual differences. Thus, the computer experiences of the participants are as well questioned, i.e., the frequency and time they use computers and the internet as well as the purposes that they use computers and the internet.

6.3. Results of Study I

6.3.1. Descriptive analysis

6.3.1.1. Computer and internet experience

In this study, the participants were asked about the ownership of a computer, the purpose of using computers, and the frequency of using the computer. The experience of computer and internet use would have an impact on the confidence of learning and controlling the application, as well as the competence of spatial ability, computer knowledge, or the evaluation of the application (cf. Schuster, 2015). All the participants use computers for private use, working, or studying. 97% of the students in vocational and technical education have their computers, and they use the computer about 23 hours per week ($M = 23.37$; $SD = 17.69$). 95.2% of the students in commercial and technical fields use computers circa 13 hours per week ($M = 13.20$; $SD = 22.05$).

The following graphic shows what kinds of computer applications are used in the students' daily life. 29 % of the participants in Group 1 use the computer to play computer games, while 69 %

of the participants in Group 2 play computer games. The document processing software is being used frequently (99 % in Group 1 and 95 % in Group 2). Nearly all the participants in Group 1 use a computer for presentation purposes (99 %).

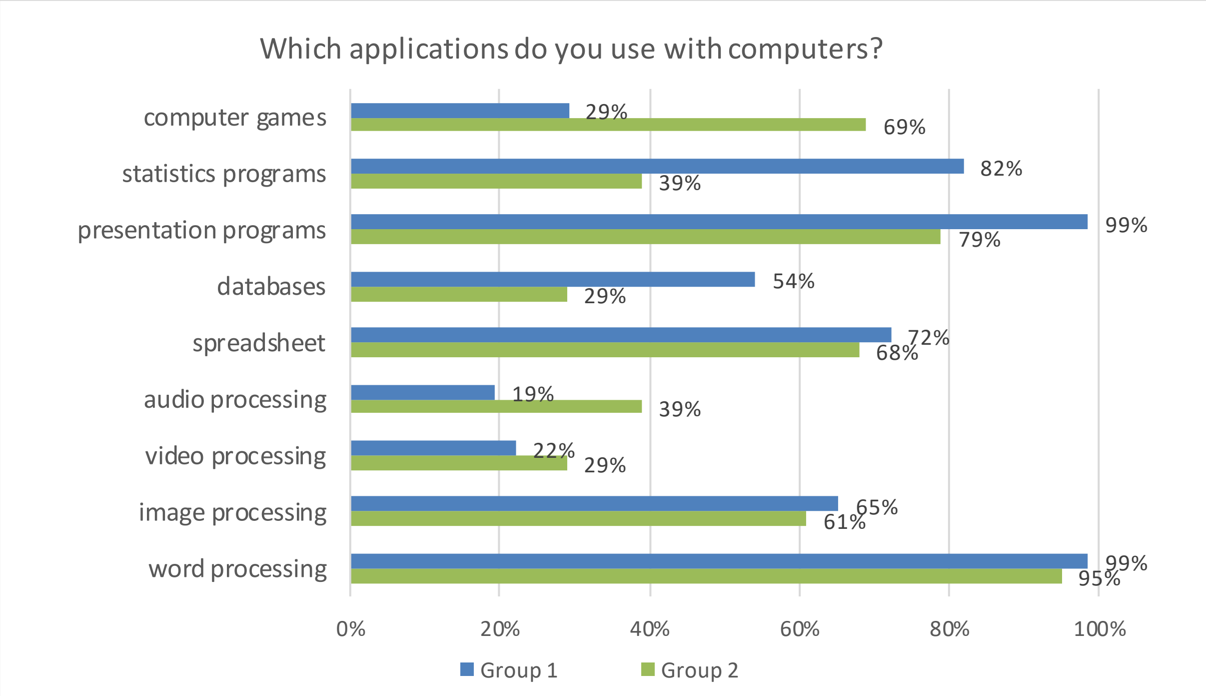

Figure 6-3 The graphic of computer application use (source: own presentation)

The purpose of using the internet and the frequency of using the internet were also surveyed in the questionnaires. The data of future teachers indicates that they use the internet for 17 hours per week on average. The data of the students in commercial and technical fields shows that they use the internet c.a. 20 hours per week.

The following graphic shows what the students use the internet for. Over 80 % of the participants use the internet for email, searching, social network, and online shopping. 21 % of the participants in Group 1 play online games, and the percent of that in Group 2 is 61 %.

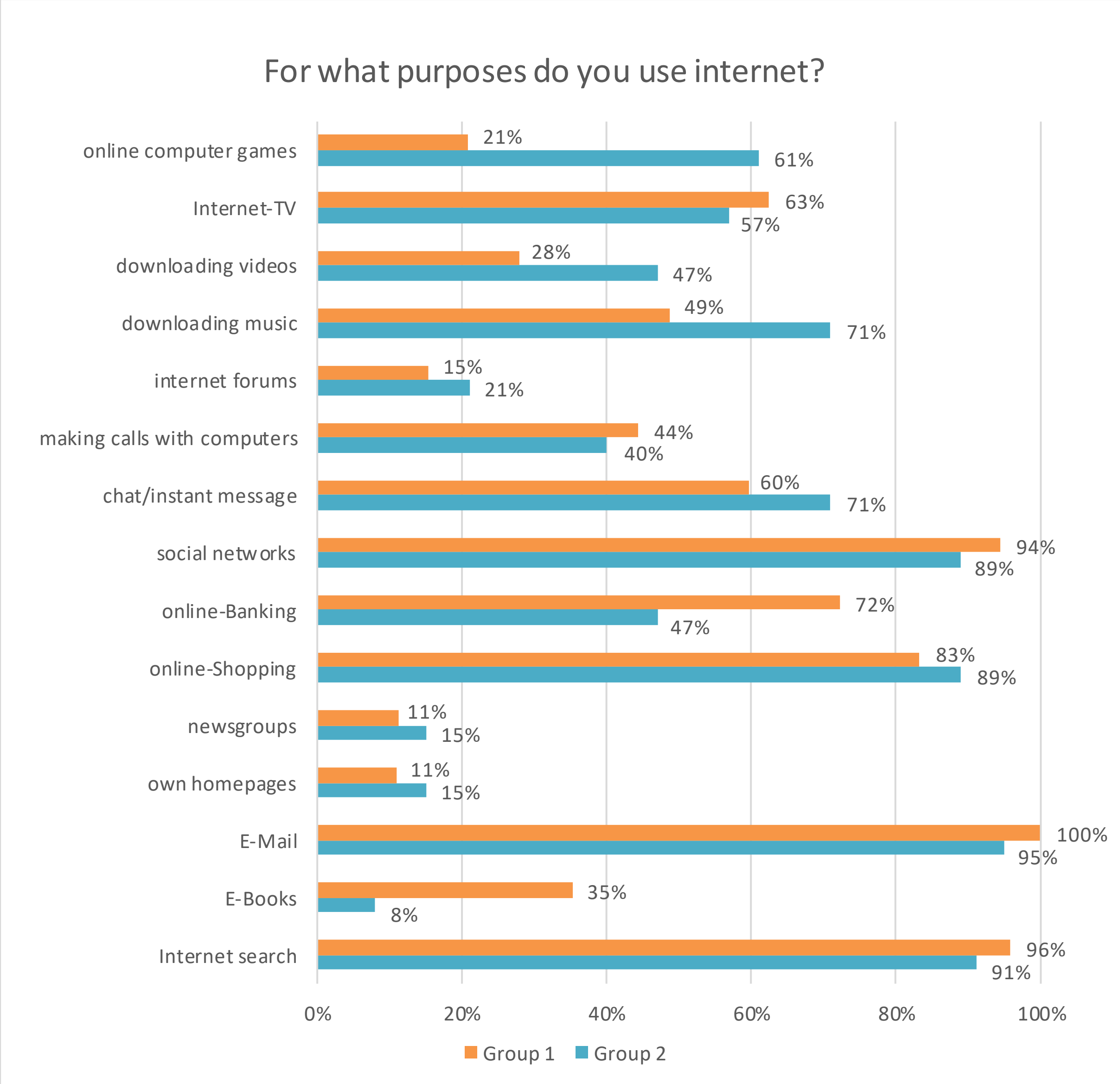

Figure 6-4 The graphic of internet application use (source: own presentation)

6.3.1.2. Study and working interest

The following table indicates the relatively high evaluations of study and working interest of Group 1 and Group 2 in the dimensions of intrinsic character (example item: "I am sure that I have chosen the training that suits my personal inclinations."), feeling-related valence (example item: " After a long weekend or vacation, I am looking forward to my training again."), and value-related valence (example item: "It was of great personal importance for me to be able to do my training in this profession.") (The scale is from 1 = "disagree" to 4 = "agree"). The scores of the reversed items were reversed in the analysis. The participants show overall high interest and positive engagement in professional activities and appreciate the significance of the activities.

Table 6-7 The value of dimensions of vocational and study interest (source: own presentation)

Dimensions	Group 1			Group 2		
	n	M	SD	n	M	SD
Intrinsic character	72	2.90	0.56	62	2.90	0.56
Feeling-related valence	72	2.71	0.51	62	2.62	0.53
Value-related valence	72	2.87	0.63	62	2.81	0.44

6.3.1.3. Spatial presence

The experience of spatial presence refers to the sensation of being present or spatially immersed in the VR environment. The mean value of individual dimensions of spatial presence is shown in the table below, indicating that the virtual learning environment provides participants with strong feelings of spatial presence (the scale ranges from 1 = "disagree" to 5 = "agree"; the higher the value, the stronger the expression).

The scores of the dimension of the spatial situation model are higher than the other dimension, indicating that the design of the virtual environment with several rooms and the foyer provides realistic surroundings. With the navigation in the building during the learning sessions, the participants could easily recall the scenario after the learning session. Additionally, the phase of free movement and exploration at the end of the training also gives the participants the possibility to know the spatial environment.

The dimension of domain-specific interest has a lower score of all the dimensions of spatial presence, showing the interest and experience of the participants in the topic of VR technology in the context of training and learning. The dimension includes the items "I have felt a strong affinity to the theme of VR learning for a long time" and "Whenever I had a choice, I would decide to deal with the topic of VR learning", both of which have mean scores lower than the scale's average value in both groups. The participants may not have much experience with the new technology of VR as well as the application in the learning, training, or working context.

The dimension of possible action is also relatively low in the scores of the participants in both groups. The reason may be the limitation of interaction without tangible user interfaces. Although the evaluated VR platform for the study has the functions of navigation, interaction with mouse and keyboard, as well as communication with other participants, they could not manipulate the objects in the environment or conduct an influential performance in the environment actively just like in real life.

Table 6-8 The values of dimensions of spatial presence (source: own presentation)

Spatial presence	Group 1			Group 2		
	n	M	SD	n	M	SD
Domain specific interest	72	2.98	0.78	62	2.81	0.80
Spatial situation model	72	4.24	0.70	62	4.30	0.57
Higher cognitive involvement	72	3.94	0.86	62	3.29	0.94
Attention allocation	72	3.78	0.66	62	3.97	0.65
Visual spatial imagery	72	3.83	0.73	62	3.68	0.78
Possible actions	72	3.18	0.76	62	2.94	0.56
Self-location	72	3.37	0.70	62	3.19	0.78
Suspension of disbelief	72	4.07	0.81	62	3.50	0.98

6.3.1.4. Flow

The experience of flow refers to the sensation of being involved in the activities in the virtual environment. The evaluation of flow experience is high in both the group of further teachers and the group of vocational students, as shown in the table below (The scale is from 1 = “disagree” to 7 = “agree”; the higher the value, the stronger the expression). The difference in evaluations of fluency of performance between Group 1 and Group 2 is not significant. However, the difference in absorption between the two groups is significant ($t(132) = -2.933$, $p \leq 0.05$). More absorption has been experienced in a group of university students.

Table 6-9 The values of dimensions of flow (source: own presentation)

Flow	Group 1			Group 2		
	n	M	SD	n	M	SD
Fluency of performance	72	5.11	1.07	62	4.85	1.13
Absorption	72	5.18	1.04	62	4.63	1.12

In addition to the dimensions above, three items about the self-evaluated ability and the difficulty of the tasks were also surveyed. The item "Compared to all other activities which I partake in, this one is … " (scale from 1 = easy to 9 = difficult) has a mean score of 3.42 (SD = 1.87), which is lower than the average value of the scale of 5. The item of ability evaluation, "I think that my competence in this area is..." (scale from 1 = low to 9 = high), receives a relatively high value (M = 5.79, SD = 1.85). The subjective fit between the requirement on the ability with the item "For me personally, the current demands are..." (scale from 1 = too low to 9 = too high) is lower than the average value of the scale of 5 but not much lower than it (M = 4.4, SD = 1.46).

6.3.1.5. Usability

The means of the individual dimensions are in the following table, including the dimension of suitability for the task (example item: " The software VPSL does not offer all functions to efficiently handle the tasks at hand."), self-descriptiveness (example item: "The software VPSL offers a poor overview of their range of functions."), controllability (example item: "The software VPSL offers no possibility to interrupt work at any point and resume it later without losses."), anticipation conformity (example item: "The software VPSL makes orientation more difficult, due to a non-uniform design."), customizability (example item: "The software VPSL is difficult to expand by the user when new tasks arise for him."), and suitability for learning (example item: "The software VPSL requires much time to learn."). The scale is from 1 (disagree) to 6 (agree), and through the evaluation, the scores of the items are reversed.

As it is shown, the relatively high usability values indicate that the users have a positive feeling in terms of the usability of the virtual learning environment. The applied software was designed and developed with many iterations and years of applications. Therefore, the usability problems were mostly solved in the past development phases. However, concerning the new application specifically for the training and learning goals, there is still some feedback for further improvement from the participants, such as the introduction of the user interface with mouse and keyboard.

Table 6-10 The values of dimensions of usability (source: own presentation)

Usability	Group 1			Group 2		
	n	M	SD	n	M	SD
Suitability for the task	72	4.81	0.93	62	4.42	0.92
Self-descriptiveness	71	4.43	0.99	62	4.15	0.91
Controllability	70	4.61	1.03	62	4.05	1.03
Anticipation conformity	71	4.96	0.91	62	4.24	1.07
Customizability	66	4.36	1.26	61	3.94	1.01
Suitability for learning	72	4.82	1.03	62	4.69	0.93

The evaluation of an additional surveyed item, “I master the evaluated software very good” (is from 1 = “disagree” to 6 = “agree”) indicates that the participants have mainly positive perception of the operation of the virtual platform (M = 4.34; SD = 1.37; n = 134).

6.3.1.6. Motivation

The evaluation of learning motivation shows that the future teachers in vocational and technical education have higher learning motivation in virtual training than the students in vocational education, including the dimensions of perceived overloading (example item: “In the virtual learning environment, the content was too much”), perceived competence (example item: “In the virtual learning environment, I understood all the content well”), relevance attribution (example item: “In the virtual learning environment, we covered the topics, that I need for the exams”), intrinsic motivation (example item: “In the virtual learning environment, I have learned interesting things.”), identified motivation (example item: “In the virtual learning environment, it is important for me, the course content to understand.”) (The scale is from 1 = “never” to 6 = “very often”; the higher the value, the frequenter the expression.).

The high value of the dimension perceived overloading indicates that the learning content and the teaching tempo are suitable for the learners. One of the reasons behind this is that the learning session of social competence has been conducted in the traditional classroom environment many times before in the virtual environment, and the tutor also has experience in guiding the workshop. In addition to that, the tempo and content of the learning sessions were also adjusted to the virtual training and learning environments, such as the addition of the introduction phase of the technology and the environment, the adjustment of interactive methods within participants and with the objects in the virtual environment, as well as the instant feedback due to technical problems.

Table 6-11 The values of dimensions of motivation (source: own presentation)

Dimensions	Group 1			Group 2		
	n	M	SD	n	M	SD
Perceived overloading	72	4.97	0.93	62	4.99	0.98
Perceived competence	72	4.01	0.76	62	4.76	0.99
Relevance attribution	72	3.38	1.29	62	3.04	1.38
Intrinsic motivation	72	3.70	1.04	62	3.58	1.40
Identified motivation	72	3.38	1.15	62	3.43	1.18

6.3.2. Structural model analysis

In order to analyze further the relationship between spatial presence (rm), usability (us), motivation (motiv), and flow (flow), a structural equation model is built up as in the following figure.

The variables of flow, including spatial presence (rm), usability (us), and motivation (motiv), explain 73.6% of flow in the future teachers and students in commercial and technical fields ($R^2 = 0.736$). The fit statistics of the model ($n = 133$, $\chi^2 = 224.722$, $df = 113$, $P(\chi^2) = 0.000$, $CFI = 0.946$, $RMSEA (90\%) = 0.000$, $WRMR = 0.875$) indicate a good fit.

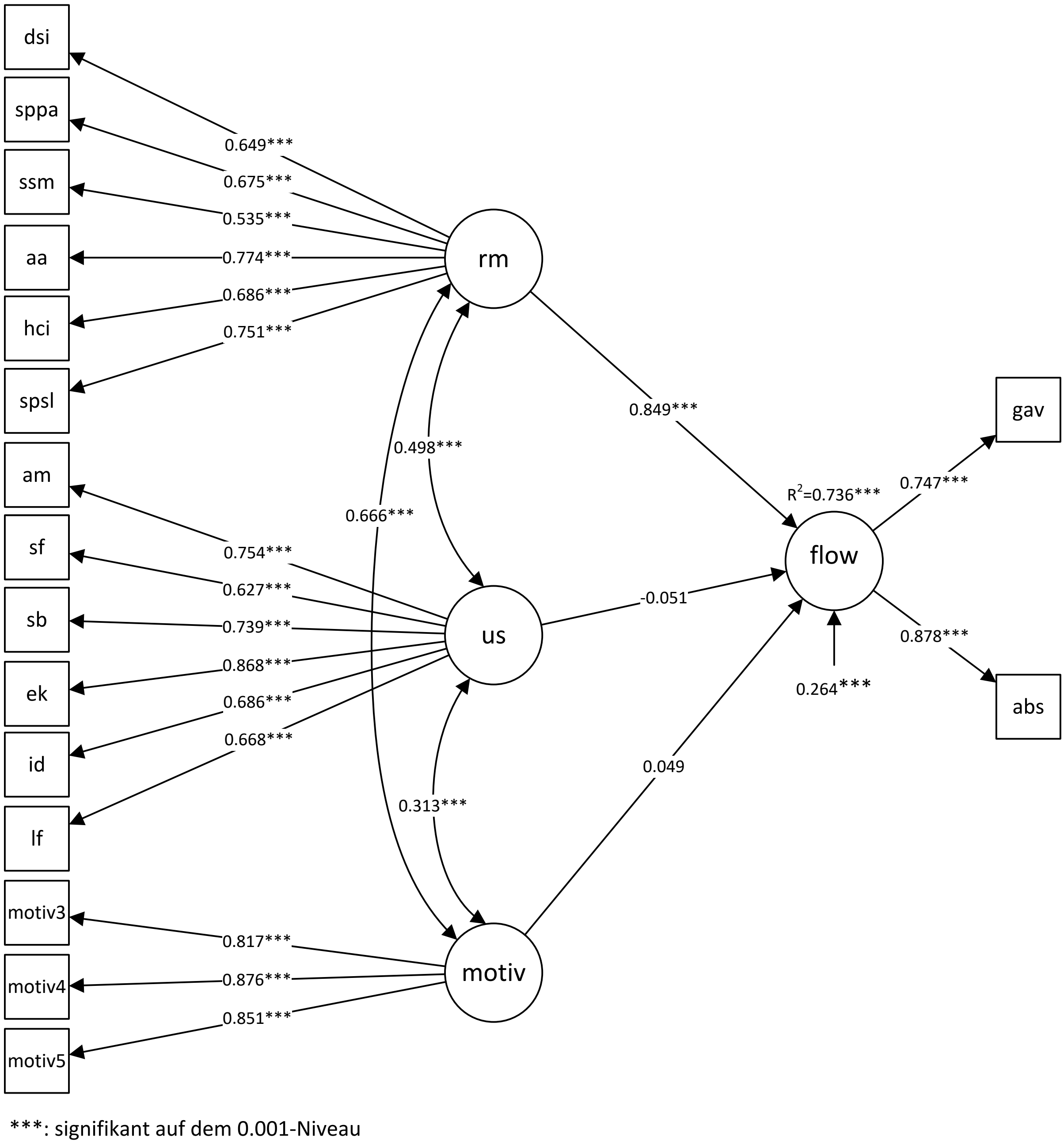

Figure 6-5 Structural equation model of flow (source: own presentation)

The model in the graphic indicates that the spatial presence has a high standardized direct effect on flow (β = 0.849). Participants who had a stronger sense of being in the virtual reality learning environment were more likely to have a deeper flow experience. Hypothesis 1 of the study is supported. The usability (β = -0.051) and die motivation (β = 0.049) have no influences on flow. Therefore, Hypothesis 5 and Hypothesis 6 are not supported by the results of the study. The structural equation model indicates significant correlations between usability and motivation (r = 0.313, p < 0.001, supporting Hypothesis 3), usability and spatial presence (r = 0.498, p < 0.001, supporting Hypothesis 2) as well as spatial presence and motivation (r = 0.666, p < 0.001, supporting Hypothesis 1).

In addition, the correlation between the mean value of spatial presence, mean value of motivation, and mean value of usability are also analyzed, indicating significant correlations between spatial presence and motivation ($r = 0.575$, $p < 0.01$, supporting Hypothesis 2), spatial presence and usability ($r = 0.475$, $p < 0.01$, supporting Hypothesis 1), as well as motivation and usability ($r = 0.399$, $p < 0.01$, supporting Hypothesis 3). Participants who had a stronger sense of being in the virtual world were more likely to have a good user experience and a positive learning motivation in the learning process. The result is consistent with the other studies with computer-mediated technologies with the positive relationships between spatial presence and motivation.

6.3.3. Results of the questions about VILA

A short qualitative interview was also conducted with 33 college students from the participants in the major of vocational and technical education to investigate the advantages and disadvantages of the application of VILA in learning and training of the social competence of perspective taking.

The results of the interview show that the participants have mainly positive feedback about the application of VILA learning settings. The feedback shows that the training practice in VILA brings the students a high level of learning motivation and a good understanding of the material.

From the realization of technology, most of the functions get a positive evaluation. The simulated visualization of the integrated cases, the individualized characters of avatars, the animations, the architectural environment, and the interactions bring the students the immersive feeling of spatial presence and the flow experience. The group cooperation, intragroup and intergroup communication, and the instruction of the teachers with their real-time synchronized voice and animation bring the students more social presence. The application of videos, websites, presentations, document files, and other tools in VILA to present the learning content by the teacher also offers more possibilities for the training processes. There are also expectations of further improvement for a better mimic simulation.

From the perspective of usability, the students with different experiences of gaming and computer operation also have a different evaluation of the ease of use of the operations with the mouse and keyboard. The students without gaming experiences find it challenging at first to master the tricks of navigation and expect a clearer explanation of the user interface with the mouse and keyboard and more time for operational practice. Due to the unfamiliar technical operations, a distraction from the learning content would occur. However, the students with gaming experience find the instruction and the operations are clear and easy to understand. This comment leads to the improvement requirement of individualization. For example, students with different levels of digital competence could experience different adaptive time plans for training procedures. Nevertheless, enough attention to the instruction phase of the training in VILA should be paid.

During the training processes, some practical issues exist, such as slow internet speed, defective sound part of the computer, firewalls of the intranet in the companies. It means that the praxis with VILA should not only focus on the ideal environment with fluent learning procedures but also take the problems into consideration, which are possible because of the realistic limitations of the practical environment, such as schools or companies.

From the perspective of training procedures, this is the first time that the VILA is implemented for these participants, who indicate that the time is not enough, and the learning content could be more. The time that the students are getting used to VILA could be saved in the following sessions. The students also indicate that, although the possibility of remote teaching and learning with VILA is promising, it needs the self-disciplinary and self-learning competence of the students.

6.4. Discussion of Study I

This study was conducted to provide theoretical and practical training for learners in the mechanics and plant engineering fields in vocational education using the technology of virtual reality.

The descriptive statistical analyses of usability, spatial presence, and flow indicate overall positive evaluations of VILA, meaning that most of the participants have a positive evaluation of the training and learning process. The developed structural equation model shows that the variance of flow is mainly influenced by the spatial presence. Usability and motivation have no significant influence on the flow experience of learners. The correlation between spatial presence and usability is significantly positive, which corresponds to the theoretical studies in the previous chapters. The results of the interview study show that the didactic-methodical processing of the learning content in the virtual environment is closely related to the contextual and situational integration of VILA.

Although virtual reality technology is innovative in the training and learning environment, whether the teaching and learning method is meaningful or effective for vocational educational praxis depends on learning content, didactical processing, situational integration, and other aspects of vocational education.

The virtual training and learning environment of VILA offers a flexible learning environment from the perspective of time and space in addition to the traditional working and learning with the function of collaboration and communication for the industrial service field. The virtual learning environment presented in this chapter was shown to be effective in the learning of declarative and procedural knowledge and promising in further application scenarios in the industry, such as service for customers, training of distant technical service, and learning of troubleshooting or maintenance for products.

The results of both the quantitative and qualitative surveys in this study will be considered to be the improvement points in future studies. The virtual reality technology used in this study is mainly based on desktop user interfaces, navigating with the mouse and keyboard, and visualizing with monitors. Since this study indicates the strong impact of presence feeling, which is the main character of the technology of virtual reality, it is interesting to investigate whether it has a similar effect with the immersive version of VR technologies, navigating with controllers and visualizing with the immersive VR glasses. Therefore, in the next chapter, a study in the virtual reality physical experimenting laboratory with the hardware of transportable VR glasses will be conducted to evaluate the usability, learning motivation, spatial presence, and the flow experience and to exam the presence effect on the flow experience of the students, which is a meaningful construct in the learning process.

7. Study II: An Empirical Study with Virtual Reality with Immersive Interface[46]

Digitalization has a great impact on learning and working space in the automobile industry. The virtual collaborative multidirectional system has been an important part of the knowledge transfer in the working area between the professional workers, especially during the problem-solving processes (cf. Karges, 2019).

With the increasing development of innovative technology in academic and economic fields, as well as within the realm of the digitalization in schools and "vocational education 4.0", in addition to the applications in the industrial vocational and further education in Chapter 6, there is a growing tendency of the implementation of various modern technologies into school teaching and learning (cf. Zinn, 2019), ranging from the application of digital tablets and 3D printing to the embracement of virtual reality (VR), augmented reality as well as artificial intelligence (cf. van Ackeren et al., 2019).

In this chapter, a study with a virtual physical sensor laboratory (VPSL) will be presented, showing an immersive and interactive technology for the praxis in vocational education as well as its required learning didactics. In the study of VILA, the interaction and immersion of the user experience of the learners are limited to the design and the development of the settings. Due to the desktop equipment, the learner could only face the 2D monitor. Due to the design of the environment, the learners could not conduct the interactions which are near to real interaction, such as grabbing, throwing, head, and body turning. The learners could only interact with the objects in the virtual environment with a mouse and keyboard, which would still reduce the spatial presence and flow experience of the learners in the virtual environment. Therefore, in the study of VPSL, the learning setting is conducted with the immersive virtual reality glass, and more interactions are embedded, which will be explained in detail in this chapter.

[46] Parts of the description of VPSL, the experimental design and the results in this chapter were published in the article by Guo et al. (2019). This study has been funded within the project "Lehrerbildung an berufsbildenden Schulen 2 im Rahmen der Qualitätsoffensive Lehrerbildung" by German Federal Ministry of Education and Research.

7.1. Research background

Despite the fast development of the VR-technology and the broad application in the field of customer marketing, the delay of the implementation of the novel technology in school education reveals the invisible hesitations of the schools, related to the shortage and the weakness of the technical infrastructures such as high-speed internet connectivity, the financial support, as well as the corresponding competence of teachers, such as the understanding of the technical didactics with the new technology, the development of the digital course modules as well as the implementation of the courses in practice. To integrate VR technology into the instructional settings in schools, the VR application should be aligned to curriculum standards and technology standards, linked to formative assessment, and supported by professional development (cf. Richards, 2017).

In the context of autonomous driving in the mobility of the future, the topic of sensors is among the most critical factors for the industry. For students in related majors, it is important to understand the physical theory of sensors, practice the physical experiments, as well as comprehend the whole working system of sensors. The VR application of VPSL developed by Ditton (2018) with the learning content of physical sensors in automobiles aims at the combination of various teaching and learning methods. VPSL is designed to be integrated into a completed class course in schools or available as an additive learning method for daily learning. The detailed setting of the virtual reality environment will be explained in the next sections.

Virtual Reality offers the possibility of situational knowledge transfer and flexible learning, which are independent of the learning location and learning time (cf. Ariali & Zinn, 2018; Zinn, Guo, & Sari, 2016). The simulation of a physical experiment enables not only the presentation of virtual objects and the information in VR but also the visualization of the elements that are not visible in the real world, such as atoms, electrons, and waves (cf. Blümel et al., 2010; Tipler & Mosca, 2015). The interactive function in the simulated environment exists already in the computer-based or internet-based learning method (cf. Hoffmann et al., 2016; cf. Schuster et al., 2014). For example, the experimental equipment can be overserved from different perspectives and programmed to be real-time changeable and variable with regard to the operations conducted by the students.

In the design and development of the course modules with virtual reality, it would be essential to incorporate empirical research in order to examine the learning and teaching experiences in VR environments. Therefore, the developed virtual reality physical sensor laboratory (VPSL) with the technology of VR should be investigated, what kind of user experience it can bring to the students as well as how it can be implemented into school teaching and learning.

As shown in Chapter 3, the flow experience of the student is mainly influenced by the spatial presence, that usability and motivation have no significant influence on flow, and there is a significant correlation between spatial presence, usability, and motivation. The research setup is based on the technology of virtual reality in the desktop version. It is interesting to investigate whether the relationships between the constructs of the user experience that are related to learning and training in vocational education have similar effects in a more immersive version of virtual reality.

7.2. Experimental design

7.2.1. Experimental setups

The whole virtual laboratory is integrated with the descriptions of the physical phenomena of the sensor experiments with the didactical preparation (cf. Reif, 2016; Tipler & Mosca, 2015) as well as the technological instructions. The students use teleportation with the controller to navigate between different experimental stations and interact with the objects in VPSL, for example, picking up the mass cubes with a laser in the force sensor experiment, changing the amount of the rainwater with a slider in the rain sensor experiment, switching on and off of the visualization of the pipe, oxygen, and exhaust gas in the lambda sensor, moving the reflection plane in the distance sensor experiment, as well as changing the magnet field shown with visible electrons and the speed of the wheel indicated as the analog waves on the oscilloscope (Figure 7-2).

Considering the limitations of the implementation of VR in schools from the financial, technical, and personal perspectives, and based on the comparison between the different contemporary hardware (e.g., the computer-based and room-scaled VR head-mounted display, the mobile phone compatible VR headsets) from the aspects of the price, the usability, and the required technical support, the standalone VR headset "Oculus Go" (resolution: 2560 x 1440; system-on-a-chip: Snapdragon 821; headset: 3 degrees of freedom; controller: a wireless orientation-tracked controller; audio system: build-in speakers) was finally chosen for the implementation of VPSL. First, “Oculus Go” has a lower cost than the other high-end VR glasses (e.g., HTC Vive) and better quality than the other mobile phone integrated VR glasses (e.g., Samsung Gear VR) according to the practical development processes. With a lower financial cost, the purchase of the equipment in schools for a whole class would be possible so that the students can immerse themselves in the VR learning environment at the same time without waiting and standing in lines. Second, “Oculus Go” is lightweight and standalone, functioning without computers or other lighting sensor stations. The user interface of “Oculus Go” is not complicated because of its high compactness. The glasses themselves are light weighted. The user could wear it for a longer period than other products without feeling the strain from the weight. Regarding the development software, VPSL was designed and developed with the development platform Unity 2018.2, as well as the 3D graphics design and modeling software SketchUp Pro 2018 and Blender 2.78.

Figure 7-1 Applied VR headset Oculus Go in the study VPSL (source: own presentation)

7.2.2. Learning content

Experimenting in schools plays an important role in knowledge transfer and learning motivation in physical learning. Lindlahr (2014) developed a VR-Physic-Experiment-Application with an interactive panel. His study indicated that the additional representation in the virtual world brings students further meaningful learning experiences in addition to the real-world experiments (cf. Lindlahr, 2014). VPSL includes five interactive physical sensor experiments in the VR environment, namely, the experiments of the rotation speed sensor, lambda sensor, distance sensor, rain sensor, and force sensor, which are closely connected to the educational plan (cf. Guo et al., 2019; Ministeriums für Kultus, Jugend und Sport Baden-Württemberg, 2013; 2016).

As shown in the following figures, in addition to the interactive board with introductions and demonstrative experiment stations, there are five experiments realized in VPSL. For every experimenting station, students should read the instructions and the physical theoretical knowledge on the interactive blackboard and conduct the operations parallelly as instructed.

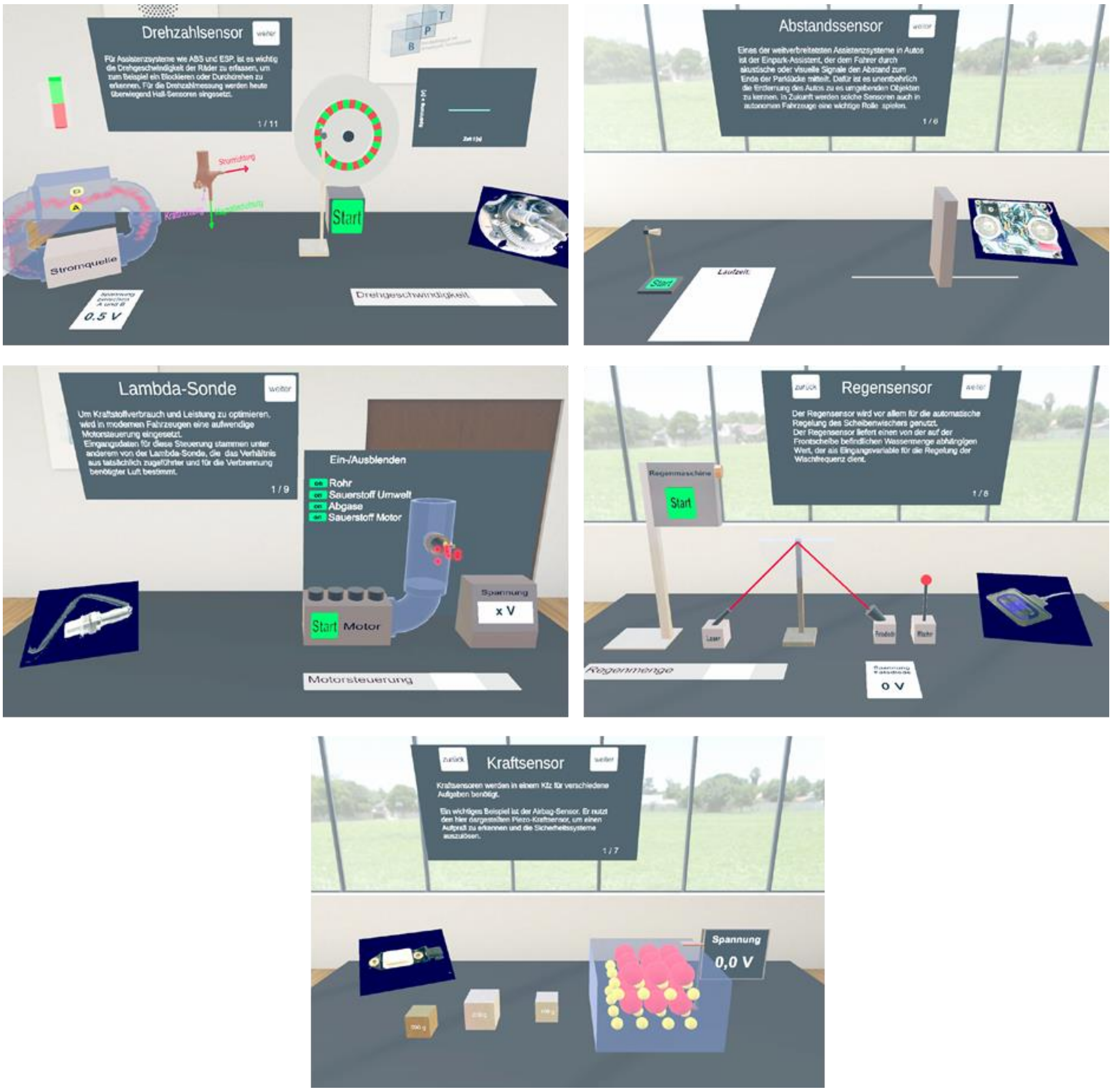

Figure 7-2 Virtual experiment setups in VPSL (Guo et al., 2019)

For the experiment of the rotation speed sensor, students could change the position of a magnet to affect the diversion of the electrons and change the displayed analog sine curves on the oscilloscope to understand the knowledge of the Hall Effect and the Lorenz force. The second experiment is the Lambda sensor experiment with the explanation of the air-fuel equivalence ratio with the interactive possibilities of changing the amount of the fuel for the engine as well as switching on and off the visualization of the pipe, the oxygen molecules, and the exhaust gas. The distance sensor shows the students a virtual visualized ultrasonic sensor with the waves transmitting and reflecting. The students can change the distance between the starting position and the reflecting wall while the distance, the speed, and the time used are calculated. The rain sensor works with the animation and visualization of the led and the photodiode, whose laser intensity would be different due to the change of the simulated water falling on the rain sensor represented by a glass disk, which is controlled by the students. The amount of rain will be reflected by the rain wiper in the experiment. The experiment with the force sensor presents the theory of the piezoelectric effect and the crystal structure by letting the students place the weights onto the sensor and showing the changing of the voltage (cf. Ditton, 2018).

7.2.3. Learning procedures

Before starting the VPSL course, the introduction of the purpose, the equipment, the personnel, as well as the cautions of the study VPSL, are presented by the instructor to the students. In the introduction phase, the students should be aware of not only the relevant information about the experimental study, the interaction with the equipment in the virtual world, and the experimenting procedures in this study, but also, more importantly, the safety cautions in terms of the hygiene issues, the physical movement and the motion sickness. Additionally, the issue of data protection was also brought to teachers and students.

During the course, the students worked in pairs or groups of three participants because of safety considerations. Namely, the student without the VR glasses should protect the student with the VR glass in the group so that the participants in the virtual world experimenting will not bump into and stumble over the desks and chairs in the classroom and hurt themselves.

In the virtual world, the participants followed the instructions on the information boards, read the physical theoretical background of the experiments, conducted the physical sensor experiments, and filled out the working sheets related to the physical knowledge gained from the experiments. After the VR course, the participants filled out the questionnaires about spatial presence, flow experience, usability, and learning motivation.

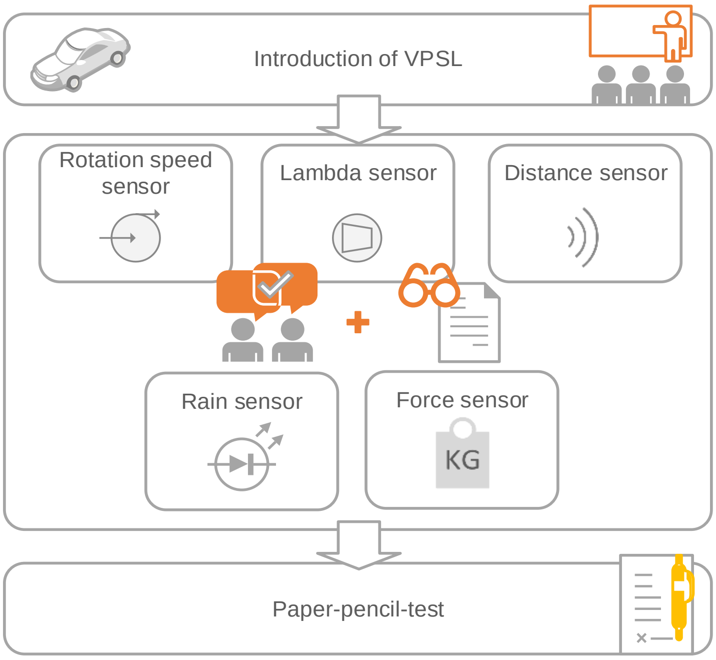

Figure 7-3 Learning procedures of the study VPSL (source: own presentation)

7.2.4. Methodology

The study focuses mainly on a systematic evaluation of the development of the virtual reality environment VPSL on the constructs of spatial presence, flow experience, and motivation based on the theoretical foundations. The demographical data of the age and the frequency of the game playing of the students were also surveyed and analyzed.

7.2.4.1. Participants

In order to evaluate the virtual learning environment in the school praxis, the study was conducted in the classes in vocational schools. The students are in the major of mechanical and electronic technicians for automation technology, which is the focus of the learning content of the physical sensors in VPSL. The total groups include 145 students between 15 and 26 years old ($M = 18.6$, $SD = 2.24$). In the majors of mechanical and electronic technicians for automation technology, the distribution of male and female students is somewhat uneven. There is only 7.6 % ($n = 11$) of the participants who are female and the other 92.4 % are male ($n = 134$). In this study, the limitation of the sex distribution indicates that the results of the study may not be totally applicable to other majors in vocational education, where the distribution is different. The study was carried out between October 2018 and April 2019.

Table 7-1 Demographic data of the participants (source: own presentation)

Participants	Students in vocational education (mechanical and electronic technicians for automation technology)			
	n = 145			
Gender	Male		Female	
	134 (92.4 %)		11 (7.6 %)	
Age	M	SD	Min	Max
	18.6	2.24	15	26

7.2.4.2. Measurements

Spatial Presence is investigated with the questionnaire of MEC-SPQ (MEC Spatial Presence Questionnaire) (cf. Vorderer et al., 2004; cf. Wirth et al., 2008), which was developed and validated in an international project (Presence: Measurement, Effects, Conditions - MEC) with different types of media. The research group proposed a two-level model of spatial presence, indicating the preconditions of spatial presence (Chapter 4) and the elements that influence the preconditions (e.g., domain-specific interest) (cf. Wirth et al., 2007).

The surveyed dimension is already in Chapter 6 introduced. In this study, each dimension of spatial presence self-location, possible actions, domain specific interest, spatial situation model, attention allocation, visual spatial imagery, suspension of disbelief, higher cognitive involvement (Table 7-2) consist of eight items with a five-stage rating scale (from 1 “I do not agree” to 5 “I agree”).

The flow was investigated with the adoption of the questionnaire of Flow Short Scale (cf. Rheinberg et al., 2003) with two sub-dimensions, fluency of performance and absorption by activity, with a seven-point rating scale (from 1 “I do not agree” to 7 “I agree”). Fluency of performance describes the utmost and unintentional concentration, the optimal feeling of control, concrete action goals and clear feedback, and smooth and logical action sequences. Absorption is the feeling of full involvement, an altered perception of time, and a loss of reflexivity and self-awareness (cf. Rheinberg et al., 2003).

Table 7-2 Reliability of dimensions of spatial presence (source: own presentation)

Dimensions	Items	Cronbach's α
Domain specific interest	8	.878
Spatial situation model	8	.840
Attention allocation	8	.936
Visual spatial imagery	8	.866
Possible actions	8	.871
Suspension of disbelief	8	.748.
Higher cognitive involvement	8	.830
Self-location	8	.925

Table 7-3 Reliability of dimensions of flow (source: own presentation)

Dimensions	Items	Cronbach's α
Fluency of performance	6	0.804
Absorption by activity	4	0.639

The participants were also surveyed about their motivation, which was adopted from the instrument developed by Prenzel et al. (1996) with a six-stage rating scale (from 1 "never" to 6 "very often"). The evaluated subscales are intrinsic motivation, identified motivation, perceived overloading, perceived competence, and relevance attribution. Intrinsic motivation takes place not only because of intrinsic incentives but also because of subjective significance and subject-specific competencies. Identified motivation describes voluntarily and largely self-determined learning when the person engages in content and activities that are neither appealing nor distressing to them, but it is necessary and essential for achieving self-directed goals (cf. Prenzel et al., 1996).

Table 7-4 Reliability of dimensions of motivation (source: own presentation)

Dimensions	Items	Cronbach's α
Perceived overloading	3	.766
Perceived competence	3	.805
Relevance attribution	3	.788
Intrinsic motivation	3	.905
Identified motivation	3	.714

The usability of the virtual learning environment was surveyed with the questionnaire developed based on the Isonorm 9241/10 (cf. Europäisches Komitee für Normung, 1995) and the Isometrics (cf. Gediga et al., 1999) with six subscales, each of which has five items with a six-score scale (from "disagree" to "agree"), including with dimensions of suitability for the task, self-descriptiveness, controllability, anticipation conformity, customizability and suitability for learning.

Table 7-5 Reliability of dimensions of usability (source: own presentation)

Dimensions	Items	Cronbach's α
Suitability for the task	5	.797
Self-descriptiveness	5	.800
Controllability	5	.784
Anticipation conformity	5	.742
Customizability	5	.901
Suitability for learning	5	.785

7.3. Results of Study II

7.3.1. Expert review

According to the study of user intention, perceived usability and perceived behavioral control in VR environments have significant effects on the use intentions of the VR technology (cf.

Pletz & Zinn, 2018). Therefore, the heuristic development processes (Chapter 3) and the expert reviews were conducted during the development process of VPSL for the optimization of the user experience.

There are, in total, 18 experts, including the students and academic researchers in the major of Pedagogics (n = 9), Software Engineering (n = 4), and Natural Sciences (n = 5) with interests in the technological and pedagogic senses. The interviews focused on the evaluation of knowledge transfer, usability, and integrated technical and professional knowledge.

The results of the evaluation indicate that the application of VPSL in physical learning is overall interesting, educational, understandable, and appropriate to the teaching content. There are also expectations of improvement, such as better graphical representation and less amount of the text, the import of gaming elements from the perspective of gamification, as well as some improvement in the interactions with the objects from the technical aspects. Based on the result of the expert review, the application of VPSL was optimized and improved for further pilot studies.

7.3.2. Descriptive analysis

The ownership states of a pair of VR glasses were surveyed. A minority of participants (5.5 %) of the participants (n = 145) own VR glasses. The result indicates that exposure to technology is still not enough, despite the vast marketing products. The reason may be the cost of the hardware and software, the complexity of the technology as well as the unacceptance of the new technology, which could also be interesting to investigate.

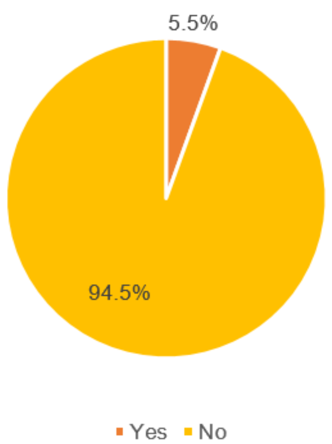

Figure 7-4 The ownership of the VR glasses of the participants (source: own presentation)

The participants were asked to state their frequency of playing computer or console games (n = 144; one participant gave no answer). The students' frequency of playing computer or console games was surveyed and distributed evenly (never: 22.2 %; one to three times per month: 27.1 %; one to three times per week: 21.5 %; more than three times per week: 29.2 %).

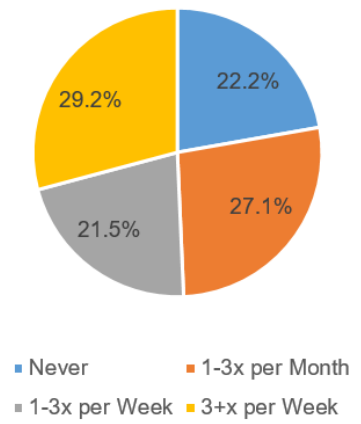

Figure 7-5 The frequency of playing computer or console games (source: own presentation)

7.3.2.1. Spatial presence

The mean values of the most dimensions of spatial presence are both larger than the scale average value (3.00), which indicates that the students have a high presence and immersive level in VPSL, for example, on the subscales of self-location (example item: “I felt like I was actually there in the environment of the presentation.”) and possible actions (example item: “I felt like I could move around among the objects in the presentation.”). Figure 7-6 gives an overview of the evaluations on the eight dimensions.

As shown in the figure, the value of the evaluation of the dimension of domain-specific interest is under the middle score of the scale (M = 2.65, SD = 0.85), which is based on the experience or the interest of the students in the VR learning context. For example, the score on the experience related items such as the item “In the past, I have spent much time dealing with the topic of the VR learning” or the item “I just love to think about the topic of the VR learning”, is lower than the scores on the other items, indicating that the students are still unfamiliar with the innovative technology. Although they may have been exposed to technology, the application of VR technology is not connected to their learning and training activities. It is also indicated in the survey of the items “I have felt a strong affinity to the theme of VR learning for a long time." and "There was already a fondness in me for the topic of the VR learning before I was exposed to it", whose scores are also lower than the average value of the scale.

As with the descriptive results in Study I, the dimension of the spatial situation model also has high scores from the participants. On the one hand, the virtual space in the VPSL environment is only one laboratory room with windows that the participants can see through. On the other hand, the six experiment stations are organized in two rows, and the room environment is simple and neat. In the immersive virtual environment, the participants could turn their heads and perceive the 360-degree environment with the headset and teleport to other positions with the controller, which could contribute to the perception of the spatial situation model of the participants.

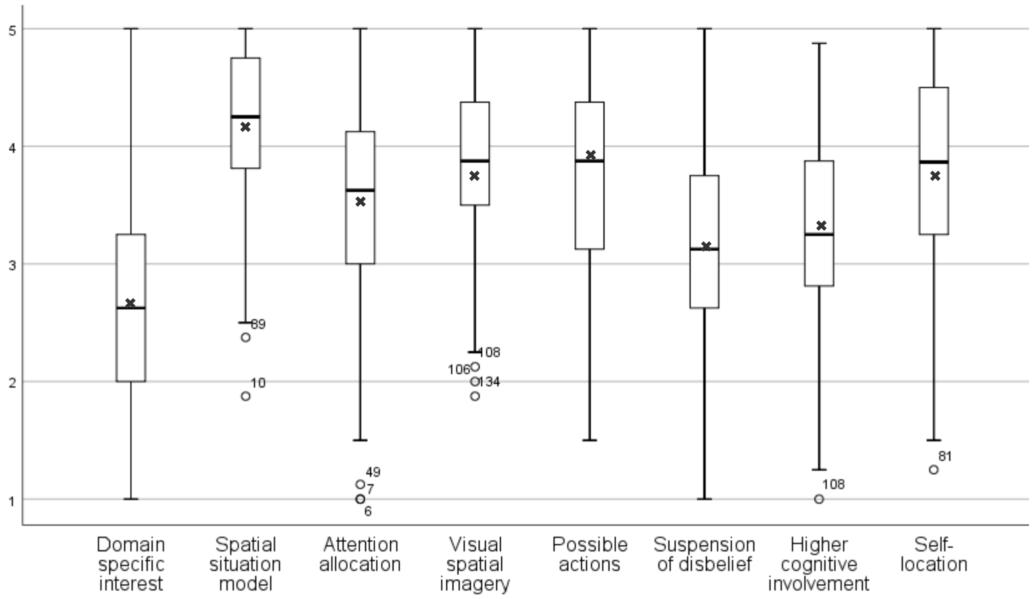

Figure 7-6 Boxplot of the dimensions of spatial presence (source: own presentation)

7.3.2.2. Flow

The flow experience of the learners is interpreted in terms of the dimensions of the fluency of performance and absorption, which are the presumed variables of the functional state in the learning activities (cf. Rheinberg et al., 2003). The evaluations of flow experience (Figure 7-7) indicate that the participants have strong experience of fluency of performance (example item: "I know what I have to do each step of the way") and absorption by activity (example item: "I am totally absorbed in what I am doing").

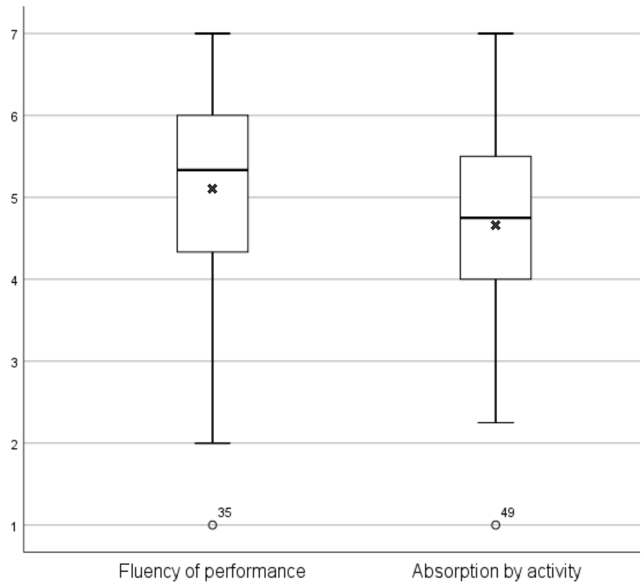

Figure 7-7 Boxplot of the dimensions of flow (source: own presentation)

Since the concern of fear would in some cases also be triggered together with the joyful flow experience (cf. Rheinberg et al., 2003), three additional items about the anxiety or concern of the learners were also surveyed about the effect of the fit between the ability and the requirement in the learning context. The result of the item "I must not make any mistakes here" has a relatively low value (M = 2.7, SD = 1.87, scale from 1 = disagree to 7 = agree) and the item "I am worried about failing" also has a low value (M = 2.6, SD = 1.81, scale from 1 = disagree to 7 = agree), indicating that the students are not afraid of failing and mistakes in virtual reality simulations.

Additionally, the result of the questioned item of the requirement for the current activity (item: "Compared to all other activities which I partake in, this one is… ", scale from 1 = easy to 9 = difficult) shifts towards "requirements are too easy" (M = 3.4, SD = 1.94). The ability evaluation of the learners themselves (item: "I think that my competence in this area is...", scale from 1 = low to 9 = high) is relatively large (M = 6.2, SD = 1.86). The subjective fit between the requirement and the ability (item: "For me personally, the current demands are...", scale from 1 = too low to 9 = too high) is lower than the average value of the scale (M = 4.4, SD = 1.74).

7.3.2.3. Usability

The participants give over positive values to the dimensions of the usability of the application

VPSL, including the dimension of suitability for the task (example item: " The software VPSL does not offer all functions to efficiently handle the tasks at hand."), self-descriptiveness (example item: "The software VPSL offers a poor overview of their range of functions."), controllability (example item: "The software VPSL offers no possibility to interrupt work at any point and resume it later without losses."), anticipation conformity (example item: "The software VPSL makes orientation more difficult, due to a non-uniform design."), customizability (example item: "The software VPSL is difficult to expand by the user when new tasks arise for him."), and suitability for learning (example item: "The software VPSL requires much time to learn.").

The scale is from 1 (disagree) to 6 (agree), and through the evaluation, the scores of the items are reversed. For example, the dimension of suitability for learning has a mean value of 4.74 (SD = 0.98), indicating that the participants could learn to use the new application without much effort.

The dimension of customizability has the lowest evaluation, which could be due to the lack of the customizing environment, learning content, hardware using habit, and other items that could be customized. For example, the VPSL has no version for left-handed users, which has been raised once during the pilot study in a vocational school. There is no customizability in the design of the virtual environment or the adaptivity of the learning content and the learning strategy of the participants.

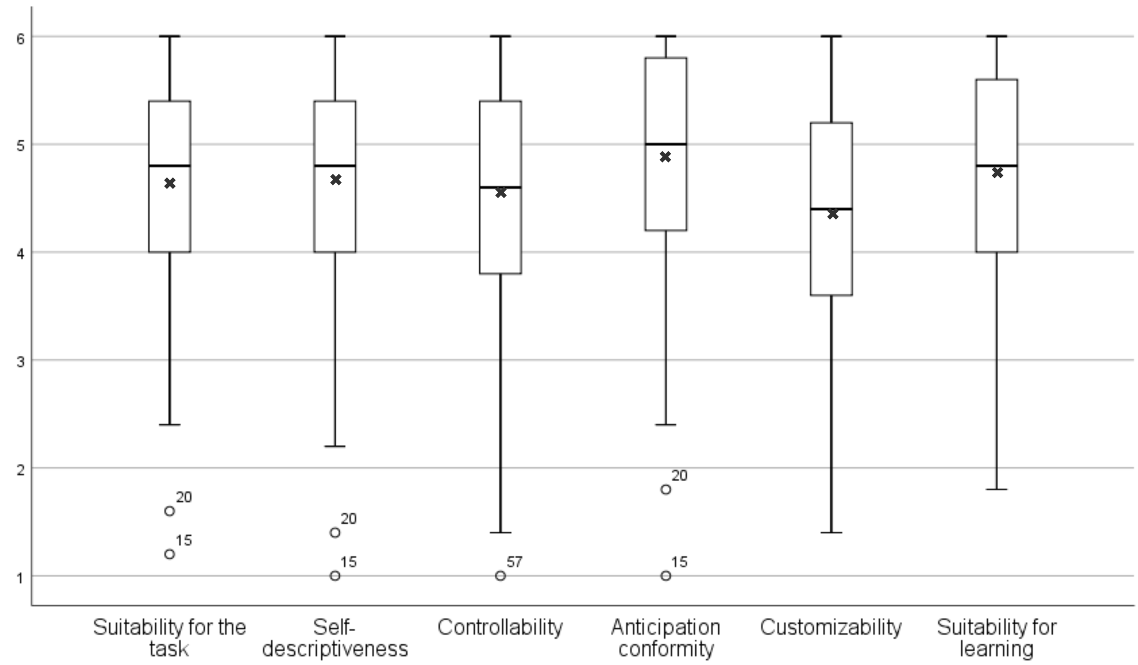

Figure 7-8 Boxplot of the dimensions of usability (source: own presentation)

The overall positive evaluation of the usability of VPSL could be attributed to the interactive design and development process and the expert review before the pilot study. Several critical usability problems were raised in the expert review and solved before the experiments in schools.

7.3.2.4. Motivation

The participants valued dimensions of learning motivation in VPSL positive, as shown by the mean values of the dimensions of perceived overloading (example item: "In the virtual learning environment, the content was too much"), perceived competence (example item: "In the virtual learning environment, I understood all the content well"), relevance attribution (example item: "In the virtual learning environment, we covered the topics, that I need for the exams"), intrinsic motivation (example item: "In the virtual learning environment, I have learned interesting things."), identified motivation (example item: "In the virtual learning environment, it is important for me, the course content to understand."), which are shown in the following figure. The scale is set from 1 (never) to 6 (very often), and the items in the dimension were reversed in the analysis.

The high score of perceived overloading shows that the participants perceive no problem with the tempo of the learning session, the capacity of the learning material, and the difficulty of the learning content. It could be induced by the setting of the learning session with VPSL. In the phase of learning and experimenting with the virtual physical sensors in the virtual environment, the participants have control of the learning tempo, such as which experiments they start to conduct, how long they spend conducting one experiment, and when they change roles in the group work.

The positive evaluation of the dimension intrinsic motivation shows that the participants have a great interest in the learning content in the virtual environment. The participants also have a positive evaluation of their competence in solving the tasks in the physical laboratory and understand the learning content.

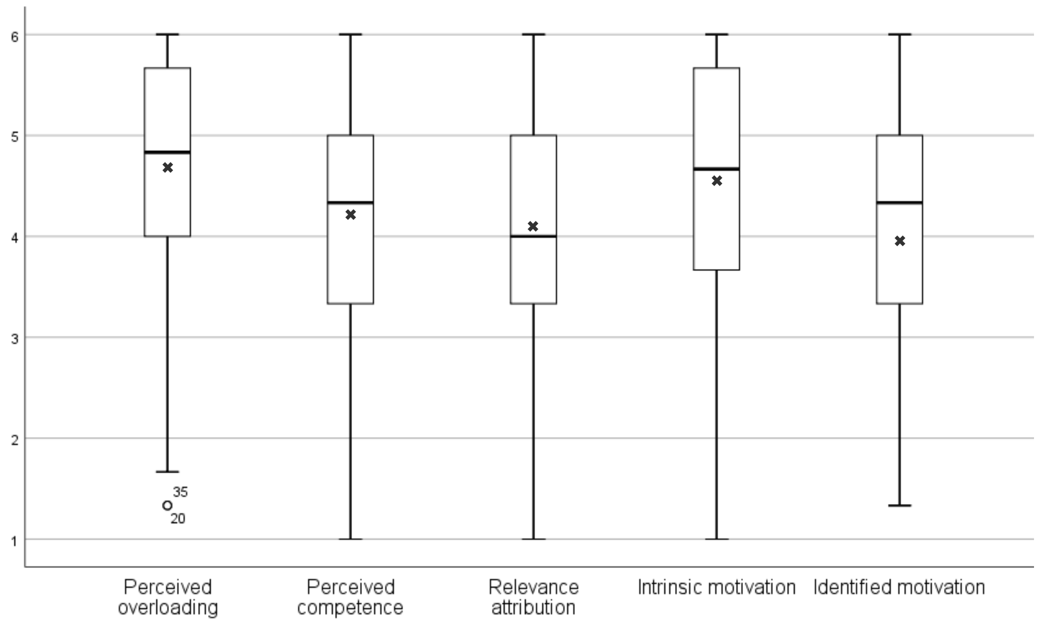

Figure 7-9 Boxplot of the dimensions of motivation (source: own presentation)

7.3.3. Structural model analysis

The relationships between the constructs of spatial presence, flow, usability and motivation are evaluated with a structural model analysis. The structure equation model as the analysis result of the study in the following figure (Model Fit statistics: n = 144, $\chi^2 = 108.731$, df = 71, p (χ^2) = 0.003, CFI = 0.942, TLI = 0.926, RMSEA (90%) = 0.061, SRMR = 0.063) indicates that the data fits the model well. The model has a variance explanation of flow experience (flow) of 81.2 % ($R^2 = 0.812$).

The model shows that the spatial presence (rm) has a significant effect on the flow experience (flow) of the students ($\beta = 0.987$, $p < 0.001$), while the motivation has no significant influence on the flow experience. Therefore, Hypothesis 5 and Hypothesis 6 are not supported, while Hypothesis 4 is supported. The structural equation model indicates significant correlations between spatial presence (rm) and motivation (motiv) ($r = 0.510$, $p < 0.001$, supporting Hypothesis 2), between spatial presence (rm) and usability (us) ($r = 0.260$, $p < 0.05$, supporting Hypothesis 1) and between usability (us) and motivation (motiv) ($r = 0.250$, $p < 0.05$, supporting Hypothesis 3).

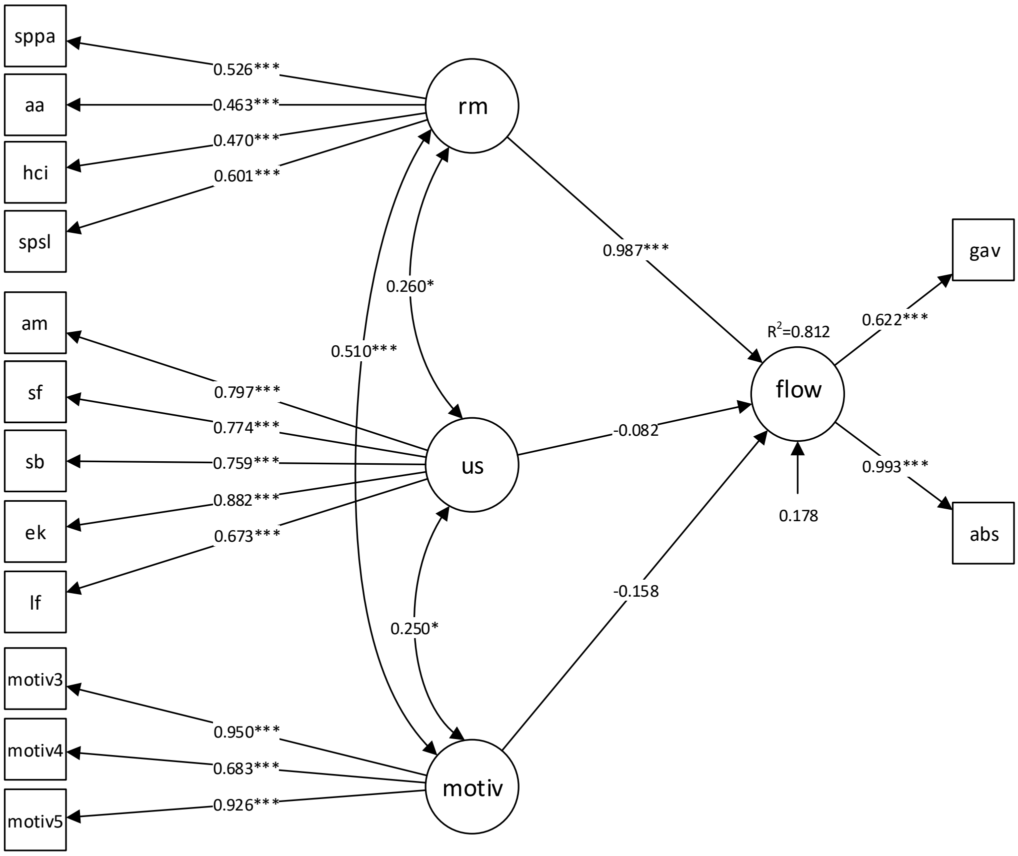

Figure 7-10 Structural model analysis of the study VPSL (***: p < 0.001; **: p < 0.01; *: p < 0.05) (source: own presentation)

In addition, the correlation between the mean value of spatial presence, mean value of motivation, and mean value of usability are also analyzed, indicating significant correlations between spatial presence and motivation ($r = 0.424$, $p < 0.01$, supporting Hypothesis 2), spatial presence and usability ($r = 0.328$, $p < 0.01$, supporting Hypothesis 1), as well as motivation and usability ($r = 0.370$, $p < 0.01$, supporting Hypothesis 3).

7.4. Discussion of Study II

This study aims at the development and pilot evaluation of an immersive virtual learning environment for the physical knowledge necessary in vocational education in the majors of Automotive Mechatronics, Mechatronics, as well as Technology and Management. Within the framework of VPSL, the perceived spatial presence, flow experience, usability, and learning motivation were surveyed with the students in the vocational schools. The descriptive statistical analyses of the surveyed perspectives indicate overall positive evaluations of VPSL.

The findings of this study contribute to the empirical research fields by providing descriptive and explanatory knowledge of the perceived user experience and flow experience by the students in vocational education in the immersive virtual environment of the virtual physical sensor laboratory (VPSL). The developed structural equation model shows that the variance of flow is mainly influenced by the spatial presence, which could be explained by the existing empirical studies in the former chapters about the relationship between flow and spatial presence (e.g., cf. Weibel & Wissmath, 2011). However, motivation has no significant effect on flow experience, unlike the results of the study of Weibel and Wissmath (2011), that motivation influences the flow experience significantly. The structural model indicates an acceptable model fit. The variance explanation of flow experience in the model is 81.2 %. The model also explains the significant correlation between the spatial presence, flow, usability, and motivation, which confirms the hypotheses of the correlations of the research.

The conduction of the VPSL course should be under certain conditions. The first condition would be that the learner has fundamental knowledge about the content of learning, such as the knowledge of optical physics, waves, and reflections (cf. Tipler & Mosca, 2015). Considering the effects of learning as well as the safety issues, the participants should have a basic operation experience of VR before they are completely immersed in the VR environment. If not, the introduction of VR and testing with the hardware and software would be necessary (cf. Zinn, Pletz, Guo, & Ariali, 2020).

With the immersive VR setups and the learning settings, several recommendations could be provided for the VR studies in vocational education with the possibilities of immersive interaction and collaboration between students. The potentially uncomfortable issues and safety issues should be warned about in the introduction phase of the learning. In the immersive virtual environment, the participant could hardly perceive the real physical environment. Especially when they have a high presence and flow experience, the participant would likely ignore the physical environment as well as the safety risks and conduct the behaviors just like in the real world, such as walking around, swinging arms, and immersing in the virtual world with the VR glass for a too long time. Therefore, the user of the VR glasses should be constantly changed between the students in the groups, or the student should pause after 15-20 minutes of immersion in the VR environment. When the participants are uncomfortable with the equipment, they are able to quit whenever they want in order to avoid safety and health problems.

Through the expert review before the massive experiments with the participants in schools, several raised problems in the usability and learning process were solved, and multiple versions of the application were developed in the iterative development process. Since immersive virtual reality technology is still underdeveloped in the educational field, there are not many experiences or standards for every technical and didactical feature of the application of the technology. Therefore, the implementation of the application should be with caution, and the design and development should utilize the principle of iterative and agile design and development.

8. Discussion and Conclusion

8.1. Summary

At the time when this thesis is written, new, creative and innovative technologies, ideas, and concepts are emerging all around the world. Although this thesis could not contain all the important perspectives on learning and training in vocational education with virtual reality technology, it gives a brief introduction of the application based on the literature research and the empirical studies. It focuses on the technical didactics and the users of the technology, including teachers, learners, and educators. The designers, developers, and the educators of the applications should make the best use of the circumstances, knowing the situation of the learning environment, the learning content, and the learning individuals and utilizing the learning methodologies, the learning technics and the relationship between the individuals and the technology.

From an economic perspective, training and learning with virtual reality technology have the advantages of flexibility in time and space, which saves time and space costs. The function of VR collaboration provides the possibilities of cloud team-working with coworkers who could be virtually presented. The simulation of the dangerous scenarios guarantees the health of the workers, and the simulation of the expensive and sensible machines saves the cost of damages. From the technological didactical perspective, the integration of the new form of virtual reality technology broadens the area of multimedia technology for teaching and learning. The technology with the possibilities of simulation, interaction, visualization, and locomotion enables an authentic and realistic learning experience, helps knowledge transfer, and supports declarative and procedural memory procedures.

This thesis provides a descriptive and explanatory knowledge of the perceived user experience by students in the virtual learning and training environment. This thesis gives a brief introduction to the application of the technology of virtual reality in training firstly and learning in the industrial and school vocational educational fields from the perspective of virtual reality technology (Chapter 2), user experience (Chapter 3), learning theories (Chapter 4), as well as two empirical studies on the application of desktop-based virtual reality in the mechanics and plant engineering training field (Chapter 6) and the application of immersive virtual reality in the physical learning field (Chapter 7). The findings in this thesis are of theoretical and practical significance, facilitating the generation of knowledge of user experience of virtual reality technology in the context of teaching and learning in virtual environments.

8.1.1. Overview of the empirical findings

This research used two different virtual reality training and learning environments for empirical studies. In this thesis, flow, defined as "being immersed in the activities in the mediated environment", is studied as a central construct of the user experience in the virtual learning and training scenarios, indicating an overall positive evaluation in both studies. Thus, the technology of VR seems to be ideal for inducing flow experiences. In both empirical studies, the subjective evaluation of the fit between the ability and the difficulty of the tasks has no big deviation from the average value but is lower than it. The participants find the tasks in the virtual environments easier than the daily training or learning tasks, no matter if it is with the learning content of social competencies or the physical sensors. According to the model of Csikszentmihalyi (2000) and other derived models (cf. Engeser et al., 2005; cf. Rheinberg et al., 2003), the moderate task requirement, along with the corresponding task ability, induces flow experience in the virtual learning and training environments.

Spatial presence, defined as the perception of "being in the simulated environment", is also highly perceived by participants in virtual environments. Both in the traditional desktop-based VR environment and with the immersive Oculus-Go-based VR environment, the participants perceived high spatial presence. As a result of the dimension of the domain-specific interest of the participants, the participants are not used to the implementation of VR technology in the learning and working environments. Although the development of technology seems to be already popular in the entertainment market, the conjunction between innovative technology and the traditional educational field is still weak.

The participants also reported overall positive evaluations of the learning motivation in the virtual reality learning environments. Despite the fact that the learning content is not closely related to school exams or daily working tasks, the participants perceive high motivation for learning in virtual reality environments. The learning and training overloading evaluated by the participants is not perceived too much. The learning and training content in the virtual environment is not perceived as very highly relevant to daily learning and working. The learning content is not designed completely the same as the tasks in the traditional classroom and industrial environments but is reconstructed from the traditional learning content, aligned with the requirements of the occupation or the teaching programs and the available features of the user experience with the VR technology.

The evaluations of usability in the two studies also indicate positive feedback from the participants. From the conduction of the studies, it could be seen that the applications still have features that need improvement. However, the participants show overall high acceptance and error tolerance for the technology and find the applications are suitable for the learning content and provide good usability. The individualization of the application is still requested by the participants. Individualization of training and learning through technology is one of the topics in "Vocational Education 4.0" (cf. Zinn, 2019). The applications for training and learning in VR could also own the technical functions of individualized characters, functions, avatars, and environments. The individualization of the learning content, learning tempos, and learning feedback are more important for further development of the training and learning scenarios.

The research results with the structural equation models show that the flow can be explained mainly by the spatial presence but not by usability and learning motivation, with a variance explanation of the flow of 73.6 % in Study I and 81.2% in Study II. The findings of the studies indicate that the designed learning virtual environments are effective by absorbing and immersing their users with a high spatial presence experience. Spatial presence plays a crucial role in enhancing the experience of flow, which was already indicated in many studies with computer-mediated technologies (cf. Schuster, 2015; cf. Voiskounsky et al., 2004; cf. Weibel & Wissmath, 2011). Therefore, spatial presence is one of the important constructs in designing a virtual reality learning environment to evoke the flow experience. The non-significant influence of usability and motivation on the flow, shown in the results of the studies, does not conform to the expectations of the studies. The results of the structural model analysis indicate that usability and motivation are not significantly influential on the flow experience.

The research also explored the relationship between the constructs of spatial presence, usability, and motivation. The results of both studies show the significant positive correlation between spatial presence, usability, and motivation, which conforms with the literature reviews (cf. Hu, 2017; cf. Lee et al., 2010; cf. Weibel & Wissmath, 2011). Dede and Richards (2017) indicate that the constructs of user experience in immersive technologies are not isolated, and the effects of the individual constructs are also hard to measure. The immersion in virtual reality alters the sense of participation of the individuals, and the constructs together influence the context, the perspective, the user experience of the participants.

8.1.2. Overview of the implementation of VILA and VPSL

This thesis expands the existing framework of UX design and development and integrates the characteristics of the software and hardware of VR technology. Although the VR training and learning environment were with the literature review and the expert review evaluated and modified in an iterative development process, further improvements based on the feedback from the empirical studies should be further conducted.

In order to design and develop the learning experience with VR technology, the iterative process will continue after this work to create practical teaching and learning materials. The design and development of a learning experience in VR are not only in the research field of pedagogics, but interdisciplinary and cross-institutional cooperation. In the laboratory, there are many creative and great ideas, most of which would only be assessed in the laboratory and never in fieldwork. For a practical, affordable, and scalable application of VR, a systematic economic assessment of the virtual learning and training compared to the traditional classroom activities and other teaching methods may also be meaningful to both vocational schools and industrial companies for further investment in the design and development of the virtual reality applications.

The current approach sets several limitations on the scenario design. The technical limitations of the 3-DoF and the resolutions of the displays mean that it is infeasible to move hands like in real life and interact with objects as in the advanced VR systems. In addition to the technical limitations, fatigue and motion sickness also limit the time and frequency of use of the VR learning systems. It is possible to foresee that the limitation would be resolved with the development of technology as well as the development of UX design in the future.

Several new VR technology systems with stand-alone glasses and 6-DoF freedom have been on the market in 2020. Although the cost of these products is still relatively high for massive use in vocational education and vocational schools, the advanced system would be affordable with the wide application and implementation of the technology in the educational, industrial, and entertainment fields.

Further implementation of other learning content would also be suitable in the virtual environments of VILA and VPSL. The implementation should be aligned with the learning and training content. In the study VILA, the evaluation of the possible interaction is low whilst the spatial conception is high, which is not the same situation in the study VPSL. The environment of VILA has an (imagined) larger navigation space than VPSL, whilst VPSL has more possibilities for physical movement and embodied interaction with the controller and the headset. The different virtual environments with various technology could provide different scenarios. In the design and development of VR training and learning, suitable technology may be the best match for the learners.

In the implementation of the application of virtual reality in school education, it is worth discussing the practical implementation with the infrastructures in vocational schools. From the standpoint of personnel training, updates to the plan of teaching and learning should be based on the current work and learning environments and incorporate innovative technology. If the teachers in vocational schools have little training or experience in the design of the learning materials for virtual reality environments, development and updates of learning scenarios with VR technology, and implementation of the educational VR application, they would have difficulties using the new technology and integrating it into the routine teaching and learning activities and building effective knowledge transfer in the learning processes. Therefore, the training of design, development and implementation of innovative technology in educational activities is necessary, which includes the systematic introduction of the didactical design with the technology, the application of learning theories in the implementation of VR scenarios, and the integration of VR with clear learning goals, learning content, and the infrastructure. Even though the use of media in the classroom has always been an integral part of teacher education or didactics in a broader sense, the technology-based worlds of experience and their associated educational potential for the professionalization of teachers should be given special consideration.

From the perspective of technological accessibility, if schools owned no corresponding hardware and software technologies, such as VR-glasses, wireless internet infrastructure, and computers with enough performance, the resources in the virtual reality world would not be effectively explored and exploited.

From the perspective of the administration, if the administrators in the school as well as the teachers in the vocational schools consider the innovation with VR technology in the educational activities unnecessary and stay with the traditional teaching and administrative modes without updates with the technological integration, the learning content would differ from the learning methods. The support of the training of the teaching personnel is necessary for the digitalization of vocational education as well as the connection to industrial firms. The industry has many developed products and production methods that are not taught or implemented in vocational education. With the help of technology and the support of industrial partners as well as the administrative personnel in schools, learning would be more practical and effective.

The main technology of VR nowadays is based on the technology of visualization and audio technology. The stimulus of the other sensors of the human body could still hardly be simulated in the virtual world, such as touching, smelling, forces and temperatures. The experience in real life is a combination of all the senses. The predefined and framed VR images and sounds limit the reality of the simulation and the embodied immersion of the users. Therefore, the focus on the goals in the design and development of the educational VR scenarios would be of great importance. The level of detail, the resolution of the applications, the abstraction of the objects, and the processes are all the facets that should be balanced.

When facilitating the VR training and learning with the participants, hygiene supplies should be equipped based on the learning and training scenarios, even for the training rooms and furniture in them. In the case of a desktop-based virtual reality environment, if the pieces of equipment are not from the participants themselves, each station should be equipped with hygiene supplies, and sanitization should be promoted when changing the users, including disinfectant wipes, hand sanitizer, disposable gloves, and other hygiene supplies. In the case of the learning session in an immersive virtual reality environment, in addition to the above-mentioned hygiene supplies, disposable VR face masks and replaceable headset face cushions would also be important. The conduction that follows the hygiene procedures provides a safe and well-learning environment, helps the learners feel safe and protected, and promotes the learning effects.

8.2. Limitations of the research and VR application

8.2.1. Limitations of the research

The studies recruited participants from college students with an average age of 24 years old and from students in vocational education with an average age of under 20 years old, who are mostly used to the technology of the internet, computers, smartphones, and tablets. The relatively young groups may be likely to ignore the limitations of the technology, have a high spatial presence, and evaluate the usability and other constructs in the VR training and learning environment positively, which conforms to the results of other studies (cf. Allen et al., 2000; cf. Pletz & Zinn, 2018)

The participants from vocational education in Study I and Study II are mainly from the majors related to mechanical and electronic technicians. The participants' group in Study II is more related to the mechanical and electronic technicians for automation technology. The empirical results of the major-homogeneous groups would be hard to be generalized to a larger participating group with a wider range of age and educational background.

The gender ratios in the empirical studies in the thesis would be critical. Since the students in the majors of mechanics and automobiles are mostly male, the male participants in the studies are the majority. Therefore, it is not possible to test whether VR learning and training applications have different effects on female and male students. Gender may still be a significant factor influencing the user experience. Concerning a heterogeneous population, the features of design and development with individualization would be important. The female participants should be taken into consideration if the applications are in schools in practice.

The questionnaires are surveyed with the participants after the learning sessions about the various constructs concerning the learning process in the virtual training and learning environments. However, the post-session feedback needs the participants to recall the learning sessions and evaluate the surveyed constructs, which could lead to an inaccuracy in the evaluation.

There are some constructs of user experience that are not empirically examined in the studies, which may also play important roles in the virtual training and learning scenarios and are interesting to study in future research. The evaluation was not focused on the social presence but on the spatial presence. In collaborative scenarios such as Study I, the social presence, the sense of “being with the other individuals in the mediated environment”, is also important to improve the immersion and learning effects (cf. Oh et al., 2018). In the immersive virtual environment of Study II, self-presence is also interesting to investigate, which is the sense of being in a virtual environment as the actual self with their own identity. Unlike the measured flow experience, self-presence focuses more on the connection between feelings to the identity, the emotions, and the virtual body (cf. Oh et al., 2018).

The component of the learning outcome is not objectively evaluated. The relationship between the user experience and learning outcomes is not clearly studied since the learning results were not objectively measured through the design of the studies. The subjective evaluation of the difficulties in the learning sessions could be undervalued by the participants without the exams during or after the learning sessions. This research focused on a formative evaluation of the description of the user experience in virtual training and learning environments. For further evaluation of the learning effects, the design of the experimenting should also be adjusted with pre-exam and post-exams as well as other control aspects.

8.2.2. Limitations of the VR application in the training and learning context

As Chapter 2 described, the application of virtual reality in training and learning in vocational education has its own limitations from both the perspective of ergonomics and the perspective of didactics. Measures should be taken for the prevention of potential risks. The goal of using technology is only achieved when we can rid ourselves of the mechanical means of reaching our intended outcome. We do not pursue the technology itself, but a means of rapidly bringing us to a remote location, an impossible scenario, or protecting us from the undesired risks. The technology will be invisible and silent to the user when the machinery functions perfectly. Effective technology allows the user to bring other experiences into their own history without changing the environment, neutralizing the space (cf. Carse, 1986).

No matter if it is for serious game design or educational application, the consideration of the possibilities and limitations of the technological environment is a sine qua non of the design, development, and implementation, such as whether it is a room-scale full-immersive VR environment or a traditional desktop-based VR environment with mice and keyboards. The design and development of the application scenario should always take the limitations of technology into consideration, including the technical data such as the refresh frame rate and the field of view as well as the didactical settings of the suitable interaction between the hardware (e.g., Controller) and scenarios (e.g., grabbing). The goal of the measures is a fluent and satisfying user learning experience, which would benefit the learning process and learning results.

On the one hand, the designer should reduce the content with potential negative effects. To ensure the safety of users, the design should prevent the users from collapsing against walls or tripping over cables (when the hardware is with cable) in the physical environment. On the other hand, the warning information should be given before the user steps into virtual reality. The technology of virtual reality has the potential to trigger shocking, repugnant, or nauseous feelings. In the case of the exhibition about mixed reality in the Art Museum Stuttgart, the users will read the notification that the appearance of flickers in VR may cause epileptic seizures before the users enter the virtual world. (cf. Hadjidjanos, 2018). Although the technical limitations of the design and development are not to be neglected, the innovation of the thought, the concept of the application, and the meaning of the content in the application behind the technology are always the most important elements that are of great importance.

From the aspect of learning theory, the learning methods, as well as learning processes in the immersive environment, differs from the traditional environment or E-learning environment, which brings some new factors to consider. The adaption of traditional teaching and learning contents into the VR environment requires close cooperation between the software-developing company and pedagogic professionals. The cognitive load in the immersive environment can also influence learning effects. The virtual environment creates a realistic and immersive world, and the information may be transferred with voices, sounds, pictures, video, or animation. The effectiveness of learning may be reduced when the rich stimulation and information for the learners is cognitively overloaded, which may hinder learners from devoting the limited cognitive resources effectively to the learning objects. Cognitive overload should be taken into consideration in the process of environmental design, the organization of the learning content, and the conduction of the teaching and learning practices in VR.

8.3. Implications and future research

There are still many open study questions in the teaching and learning field with the technology of virtual reality and many expectations for the optimization of VR applications. The experimental learning environments link virtual places with physically real learning spaces in schools, universities, and company locations. The new forms of human-technology interaction, via virtual reality technology, can make innovative (experimental) learning environments tangible and thereby support desirable practical references in vocational education. The generalizations for other VR applications seem reasonable. Further studies could investigate the issues in this thesis with other training and learning scenarios, pursuing the goal of advancing digitalization through the design, development, and implementation of VR technology in the field of vocational education. From the aspect of UX design, development, and evaluation, there are several aspects to be taken into consideration for future research.

From the results of the two studies, it is indicated that both VR learning environments provide a high perceived spatial presence and flow experience. Therefore, it is also interesting to investigate whether a lower level of immersion or a lower level of detail could yield the same benefits, as well as which components in the immersive settings could be omitted in the given training and learning settings. In a collaborative immersive virtual environment, the social presence and the self-presence, together with the spatial presence, have an influence on the user experience of the individuals and would also be meaningful to study.

It is also interesting to investigate how learners in vocational and further education can effectively participate in designing the VR learning application, as well as how digital didactical design and development using innovative technology promotes the cognitive and motivational aspects of the learning processes. The empirical studies in this thesis are focused on the user experience evaluations in virtual reality training and learning environments rather than the analysis of the learning effect of the corresponding technologies and learning settings. The learning effect analysis would be meaningful for future research, including the evaluation of knowledge transfer and competence development with the VR technologies, such as whether the VR applications improve the understanding and performance of perspective-taking competencies of the participants or whether the VR applications improve the understanding of physical knowledge.

The participants in vocational education in the two empirical studies have an average age of around 20. The participants from the university are also in a young age range. The evaluation of the user experience was in accordance with the expectations for the age groups. In further studies, the user-centered design and development of a virtual learning and training environment should not exclude users in other age groups and other conditions.

This thesis indicates a description of a virtual learning and training environment with several hardware and software settings. The two empirical studies presented in this thesis are with different technologies. The study with VILA uses the multi-user-based and desktop-based virtual learning environment. The study with VPSL uses a single-user-based and immersive virtual learning environment. However, it is meaningful for further studies with enough technological development to utilize the multiuser-based and immersive virtual reality training and learning environment and to realize an authentic, collaborative and immersive training and learning scenario. The location-independent settings would bring new connections and nurture new relationships in teaching and learning afar, locally and globally.

The further implementation of a virtual platform would be popular and user-friendly if it is based on a cross-platform technological and didactical framework without the limitations of the interfaces. There are nowadays various technologies with application functions, such as computers, tablets, mobile phones, VR glasses, AR glasses, and other smart equipment. The cross-platform application would be, in this case, more applicable and suitable for different students with different equipment. The learners could use their own devices instead of buying new uniform smart appliances for each learning scenario requirement, no matter whether it is a desktop-based interface, a smartphone-based interface, or an immersive virtual reality interface.

From the perspective of the possibilities of the natural user interface, although further interactive equipment such as the data gloves, the eye-tracking systems, the body-tracking systems, and the 360-videos are not implemented in this research, it is conceivable to integrate and implement the new technology of visualization, interaction, and locomotion, based on the learning environment, learning participants, and learning content, in order to build a more authentic learning experience and facilitate knowledge transfer in the learning situations. Through the integration and implementation of the natural user interface and tangible user interface, the sensorimotor activities would facilitate the declarative and procedural learning procedures, especially in the learning situations for practical hands-on skills and scenarios for virtual experiences.

With the algorithms of machine learning and artificial intelligence, the customizability and the individualization of learning scenarios could be realized in the future development, that the learning scenarios offer the appropriate learning content to the users, that the learning scenarios support the appropriate learning tempos of the students, and that the learning scenarios give suitable feedback instantly to the learners.

The implementation of further technologies and the corresponding didactics would change teaching and learning in vocational and further education, providing a new location-flexible and time-flexible construction. VR indicates the possibility of bridges between V and R, letting people realize the unlimited potential of knowledge, avoid selfish perspectives, respect others and nature, and respect the multivariate culture. VR enables the experience of others, other cultures, other scenarios, learning knowledge, reflecting themselves, and expanding the horizons of the view of training and learning in vocational education.

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