Promoting Pre-Service Teachers' TPACK Development in Social Virtual Reality

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Practice- and Theory-Oriented Development and Evaluation of a Pedagogical Concept for Initial Teacher Education

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Abstract (English)

The everyday use of digital media by children and young people offers new opportunities for participation, communication, and collaboration. However, to fully exploit this potential and prepare youths for the risks and challenges of media usage, the promotion of the digital competencies of students and teachers is an indispensable goal for educational institutions.

To meet this requirement, teacher education must be opened to innovative pedagogical concepts for initial teacher education that considers new technologies in a reflective, action-oriented way to promote competencies. Therefore, this work aims to promote the technological pedagogical content knowledge (TPACK) of prospective teachers that enables the purposeful integration of social virtual reality (Social VR) into the classroom. Consequently, a pedagogical concept is developed and evaluated in an iterative research and development process following the design-based research approach (DBR) through four consecutive studies.

The beginning of this paper introduces the theoretical approaches and concepts that form the foundation of the studies. First, TPACK is presented as a meta-conceptual awareness and target perspective for the successful integration of social VR into the classroom. To meet these requirements, the potential affordances of social VR for teaching and learning processes are outlined through a theoretical perspective. For the design and development of a pedagogical concept considering theoretical foundations and practical experiences, DBR is described as framing the work concerning research methodology.

Following DBR, Study 1 analyses and explores the existing expectations and requirements of lecturers and students regarding the goal-oriented use of social VR in the classroom. Hence, qualitative interviews were conducted with both target groups, lecturers, and students. The results show important contextual factors, such as an increased need for the supervision and support of both groups in using social VR hardware and software. Furthermore, lecturers and students want disruption-free communication and interaction processes in social VR. To address both aspects, support services, such as IT support, video tutorials, and abundant recovery breaks between teaching and learning processes are integrated as preliminary design features.

Study 2 analyzes how prospective teachers perceive teaching–learning activities in fully immersive social VR. Consequently, two teaching–learning scenarios based on the theory-driven pedagogical concept will be conducted. Qualitative interviews derived consequences for developing the pedagogical concept to promote TPACK among prospective teachers. For

example, the concept design considers principles of action-oriented teaching, flipped classroom, and students' cognitive relief through several breaks.

To develop the pedagogical concept and to concretize the design features, the third study investigates how students perceive teaching and learning processes in social VR compared to video-based communication. For the promotion of TPACK as metaconceptual awareness in social VR, the implementation of peer group supervision enables metacognitive teaching and learning processes, such as reflection and problem solving. To approach a robust intervention in an authentic setting, the seminar takes place remotely. As a central learning activity, learners create instructional designs in an iterative design process with which social VR can be used in an action-oriented manner. Qualitative data collection was conducted through guided student reflection videos and semi-structured group interviews. The results again demonstrate the necessity of breaks and runs of peer group supervision. Generally, balancing the presentation of pedagogical and technical stimuli and avoiding cognitive overload proved to be a criterion that supported learning processes.

Study 4 evaluates pre-service teachers' development of TPACK as metaconceptual awareness in social VR and Zoom. As in previous studies, students plan and design lesson plans that are iteratively adjusted after three peer-group supervisions. For data collection, students used a graphic assessment of TPACK instrument (GATI) tool to estimate their current TPACK levels before and after the seminar. Self-assessments and portfolios were coded and qualitatively analyzed using epistemic network analysis (ENA). The results reveal quite homogeneous TPACK development in both groups. However, based on participants' ENA networks in social VR, more complex connections between knowledge domains become apparent. Consequently, it can be concluded that students who regularly work with social VR in an authentic context, based on their practical experience, can purposefully derive actions for planning and designing lessons with social VR.

As the results from Study 4 indicate, the pedagogical concept successfully promoted TPACK as metaconceptual awareness. In the concluding chapter, appropriate implications for teacher education research and practice are derived from findings. For example, further in-depth investigation of the nature of TPACK as metacognitive awareness could reveal learning-enhancing aspects of teacher education for media integration in class. Furthermore, seminar contents dealing with using new technologies should account for digital literacy aspects, leading to VR use considering moral values and practiced sustainability.

Abstract (Deutsch)

Die tägliche und mittlerweile selbstverständliche Nutzung digitaler Medien durch Kinder und Jugendliche bietet neue Möglichkeiten für Partizipation, Kommunikation und Kollaboration. Um dieses Potenzial jedoch voll ausschöpfen zu können und junge Menschen auf die Risiken und Herausforderungen der Mediennutzung vorzubereiten, ist es eine wichtige Aufgabe, die digitalisierungsbezogenen Kompetenzen von Schülern und Lehrern gezielt zu fördern.

Um dieser Aufgabe nachkommen zu können, besteht die Notwendigkeit der Öffnung der Lehrerbildung für innovative pädagogische Konzepte für die Hochschullehre, die neue Technologien reflektieren und handlungsorientiert für eine Kompetenzförderung berücksichtigen. Ziel dieser Arbeit ist es daher, das Professionswissen TPACK zukünftiger Lehrkräfte zu fördern, damit diese social Virtual Reality (social VR) handlungsorientiert in den Schulunterricht integrieren können. Dazu werden im Rahmen von vier konsekutiven Studien, einem Design-Based Research Ansatz folgend, ein Lehrkonzept für die Lehrerbildung entwickelt und in einem iterativen Forschungs- und Entwicklungsprozess evaluiert.

Zu Beginn der Arbeit werden die theoretischen Ansätze und Konzepte vorgestellt, die die Ausgangsbasis für die Studien bilden. Zunächst wird TPACK, verstanden als metakonzeptionelles Bewusstsein, als Zielperspektive für die gelingende Integration von social VR im Unterricht eingeführt. Weiterhin werden die Potenziale von social VR für Lehr- und Lernprozesse aus einer theoretischen Perspektive skizziert. Für die Gestaltung, Entwicklung und Evaluation eines pädagogischen Konzepts, das sowohl theoretische Grundlagen als auch praktische Erfahrungen berücksichtigt, wird der Design-Based Research Ansatz (DBR) als forschungsmethodische Rahmung der Arbeit beschrieben.

Dem Design-Based Research Ansatz folgend, widmet sich Studie 1 der Analyse und Exploration bestehender Erwartungen und Anforderungen von Dozierenden und Studierenden in Bezug auf den zielführenden Einsatz von social VR im Unterricht. Die Auswertung der qualitativen Interviews beider Zielgruppen zeigen wichtige Kontextfaktoren auf, wie zum Beispiel einen erhöhten Betreuungs- und Unterstützungsbedarf beider Gruppen bei der Nutzung von social VR Hard- und Software. Darüber hinaus wünschen sich Dozierende und Studierende reibungslose Kommunikations- und Interaktionsprozesse in social VR. Um beide Aspekte zu berücksichtigen, werden Unterstützungsangebote, wie zum Beispiel IT-Support, Video-Tutorials und viele Erholungspausen zwischen den Lehr- und Lernprozessen als vorläufige Gestaltungsmerkmale in das pädagogische Konzept integriert.

Studie 2 hat das Ziel zu analysieren, wie angehende Lehrkräfte die Lehr- und Lernaktivitäten in vollständig immersiver social VR wahrnehmen. Dazu werden basierend auf dem Lehrkonzept zwei unterschiedliche Lehrszenarien durchgeführt. Mit Hilfe qualitativer Interviews werden Erkenntnisse zur Weiterentwicklung des pädagogischen Konzepts zur Förderung von TPACK bei angehenden Lehrkräften gewonnen. So werden beispielsweise die Prinzipien des handlungsorientierten Unterrichts und Flipped Classrooms sowie die kognitive Entlastung der Studierenden durch mehrere Pausen bei der Konzeption berücksichtigt.

Zur Weiterentwicklung des pädagogischen Konzepts und zur Konkretisierung der Gestaltungsmerkmale wird in der dritten Studie untersucht, wie Studierende Lehr- und Lernprozesse in social VR im Vergleich zur videobasierten Kommunikation wahrnehmen. Mit TPACK als metakonzeptionelles Bewusstsein als Zielperspektive, ermöglicht die Implementierung von kollegialen Fallberatungen metakognitive Lehr- und Lernprozesse, wie zum Beispiel Reflexions- und Problemlösungsprozesse. Als zentrale Lernaktivität, erstellen Lernende handlungsorientierte Unterrichtspläne für den Einsatz von social VR im Schulunterricht in einem iterativen Designprozess. Die Auswertung der angeleiteten Reflexionsvideos und der halbstrukturierten Gruppeninterviews zeigen erneut, dass weitere Pausen und Durchläufe der kollegialen Fallberatung für eine kognitive Entlastung der Lernenden berücksichtigt werden müssen. Allgemein bewies sich die Einhaltung einer Balance zwischen der Präsentation von pädagogischen und technischen Stimuli und der Vermeidung von kognitiver Überforderung als ein Kriterium, das die Lernprozesse positiv zu unterstützen scheint.

Studie 4 evaluiert die Entwicklung von TPACK als metakonzeptuelles Bewusstsein von Lehramtsstudierenden in social VR und Zoom. Wie in den vorhergehenden Studien gestalten Studierenden in drei iterativen Durchläufen der kollegialen Fallberatung Unterrichtsentwürfe. Zur Datenerhebung nutzen die Studierenden das GATI-Diagramm, um ihren aktuellen TPACK-Entwicklungsstand vor und nach dem Seminar einzuschätzen. Die Kodierung und Auswertung der GATI Diagramme und Portfolios erfolgt mittels der epistemischen Netzwerkanalyse (ENA). Die Ergebnisse zeigen, dass die Entwicklung von TPACK in beiden Gruppen ziemlich konsistent ist. Jedoch weisen die ENA-Netzwerke der social VR Teilnehmer:innen komplexere Verbindungen zwischen den TPACK Wissensdomänen auf. Aus den Ergebnissen lässt sich schließen, dass Studierende, die regelmäßig mit social VR in einem authentischen Kontext arbeiten, basierend auf ihrer Praxiserfahrung, zielführende Handlungen für die Planung und Gestaltung von Unterricht mit social VR ableiten können.

Wie die Ergebnisse aus Studie 4 zeigen, konnte das pädagogische Konzept TPACK als metakonzeptuelles Bewusstsein in social VR erfolgreich fördern. Im abschließenden Kapitel werden aus den Erkenntnissen relevante Implikationen für Forschung und Praxis in der Lehrerbildung abgeleitet. Beispielsweise könnten weitere vertiefende Untersuchungen zum Wesen von TPACK als metakognitives Professionswissen, lernförderliche Aspekte für die Vorbereitung von Lehrkräften auf den Medieneinsatz aufzeigen. Weiterhin, in Anbetracht eines Bewusstseins für Ethik und Nachhaltigkeit beim Einsatz von neuen Technologien in der Lehrerbildung, sollten Curricula vermehrt auch medienerzieherische Aspekte in Betracht ziehen.

Papers included in the article-based dissertation

Paper 1: Ripka, G., Tiede, J., Grafe, S. & Latoschik, M. (2020). Teaching and Learning Processes in Immersive VR – Comparing Expectations of Preservice Teachers and Teacher Educators. In D. Schmidt-Crawford (Ed.), *Proceedings of Society for Information Technology & Teacher Education International Conference* (pp. 1863-1871). Online: Association for the Advancement of Computing in Education (AACE)

Abstract:

The usage of VR in higher education is not uncommon anymore. However, concepts are mainly still focusing on technical rather than pedagogical aspects of VR in the classroom. The exploration of the expectations of teacher educators as well as of preservice teachers appears indispensable (1) to achieve a sound understanding of requirements, (2) to identify potential design spaces, and finally (3) to create and to derive suitable pedagogical approaches for VR in initial teacher education. This paper presents results of guideline-based qualitative interviews comparing the expectations of teacher educators and of preservice teachers regarding teaching and learning in immersive virtual learning environments. The results showed that preservice teachers and teacher educators expect VR to enrich classes through interactive engagement in situations that would otherwise be too costly or dangerous. Regarding the design, teacher educators put the emphasis on functionality. Student teachers emphasized that they do not want to miss social interactions with their peers. Furthermore, both groups stated preferred modes of collaboration and interaction taking into account the characteristics of a virtual learning surrounding such as being able to use diverse learning spaces for group work. Interviewees agreed on two vital factors for effective learning and teaching processes: flexibility and the possibility of customization considering technical properties that are to deal with. Apart from this, preservice teachers emphasized strongly their worries about data usage and the ethics regarding using avatars and agents for representation.

Paper 2: Ripka, G., Grafe, S. & Latoschik, M.E. (2020). Preservice Teachers' encounter with Social VR – Exploring Virtual Teaching and Learning Processes in Initial Teacher Education. In E. Langran (Ed.), *Proceedings of SITE Interactive 2020 Online Conference* (pp. 549-562). Online: Association for the Advancement of Computing in Education (AACE)

Abstract

With 21st century challenges ahead, higher education teaching and learning need new pedagogical concepts. Technologies like social VR enable student-centered, action-oriented, and situated learning. This paper presents findings of the pedagogical implementation of a distributed social VR prototype, a fully immersive VR learning environment, into an Initial Teacher Education program in Germany.

The exploratory study addressed the following research questions: 1) How do preservice teachers perceive teaching and learning activities in fully immersive VR and 2) how should teaching and learning processes using social VR in Teacher Education be designed? It followed a design-based research approach. The pedagogical concept for teaching and learning insocial VR was based on principles of action-orientation. A convenience sample of three groups of five students each took part in a 90-minute teaching and learning scenario using a fully immersive VR learning environment. During these seminar units, students engaged in qualitative group interviews and shared their perception of the action-oriented teaching and learning activities in VR. The results showed that preservice teachers had the feeling of being less distracted in social VR. Additionally, during group activities, missing social and behavioral cues made communication procedures more challenging for participants. However, some participants noticed a stronger sense of community while collaborating with others.

Paper 3: Ripka, G., Grafe, S. & Latoschik, M.E. (2021). Peer group supervision in Zoom and social VR- Preparing preservice teachers for planning and designing digital media integrated classes. In T. Bastiaens (Ed.), *Proceedings of EdMedia + Innovate Learning* (pp. 602-616). United States: Association for the Advancement of Computing in Education (AACE)

Abstract

21-century challenges demand a change towards collaborative and constructive seminar designs in initial teacher education regarding preservice teachers acquiring meta-conceptual awareness (TPACK) about how to implement emerging technologies in their future profession. Against this background the paper addresses the following research questions: 1) How should a pedagogical concept for remote initial teacher education be designed to promote metacognitive learning processes of preservice teachers? 2) How do preservice teachers perceive these learning processes in video-based communication and social VR? Regarding the pedagogical concept, peer group supervision and an action- and development-oriented approach using Zoom and social VR were identified as relevant for an instructional design that provides collaborative and constructive learning processes for students. In this exploratory study, 17 students participated in two iterative cycles of peer group supervision performing design tasks in groups. A content analysis of reflective video statements and qualitative group interviews was carried out using a qualitative research design. Results indicate the successful implementation of peer group supervision. Regarding media's implementation, Zoom's screen-sharing option and breakout session benefitted the consultation process as well as social VR's "realistic" experience of creating a "sense of community".

Paper 4: Ripka, G., Grafe, S. & Latoschik, M.E. (2021). Mapping pre-service teachers' TPACK development using a social virtual reality and a video-conferencing system. In T. Bastiaens (Ed.), *Proceedings of Innovate Learning Summit 2021* (pp. 145-159). Online, United States: Association for the Advancement of Computing in Education (AACE)

Abstract

Social VR's characteristics, by offering authentic learning environments that enable interaction remotely and synchronously and permit learning experiences that affect learners in a multi-sensory way, offer great potential for teaching and learning processes. However, concerning its use to promote pre-service teachers' TPACK in initial teacher education, there remains a research desideratum. In this context, this exploratory study addressed the following research question: How did pre-service teachers' TPACK develop using a social VR learning environment prototype in comparison to a video-conferencing platform throughout a semester? Following a design-based research approach, an action-oriented pedagogical concept for teaching and learning in social VR was designed and implemented for initial teacher education at a German university with a convenience sample of 14 participants. The lesson plans were collected and analyzed with the help of

Epistemic Network Analysis (Shaffer, 2017) at three points of time during the semester and the GATI reflection process (Krauskopf et al., 2018). Further, 14 GATI diagrams gave insights into pre-service teachers' self-estimated TPACK. As the results indicate, pre-service students constructed more complex mental models of TPACK in social VR compared to the video-conferencing platform, indicating that more interrelations between knowledge domains could be constructed by planning and designing VR-integrated lesson plans.

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1. Introduction

In recent years, there have been gradual changes in how the educational sector is implementing digitization. These changes manifest themselves in the educational policy documents of different countries, for example the resolution of the Conference of the Ministers of Education and Cultural Affairs of the federal states of Germany that defines two main goals for digitization in schools (Ständige Konferenz der Kultusminister der Länder in der Bundesrepublik Deutschland, 2016). As media play an integral part in the socialization of pupils (see Feierabend et al., 2020), one aim is to foster their media competencies and thus sensitize them to the use of the media, with all its diverse aspects, within the framework of school subjects. Preparing students for active and responsible participation in cultural, social, political, economic, and professional life is of great importance because of the gap between students' increasing use of digital media and their own perceived digital competencies (Cress et al., 2018). The use of digital media gives young people new opportunities for participation, communication, and collaboration, but also exposes them to new forms of self-endangerment, political extremism, hatred, and violence on the internet (jugendschutz.net, 2021). Although 14- to 24-year-olds see the advantages of accessing the internet and using social media, they feel unprepared to face the risks involved. Forty percent of the participants of the Milieu Study on Trust and Security on the Internet in 2018 even admitted being scared of the threat posed by digital media and feeling unprepared to face this threat (Deutsches Institut für Vertrauen und Sicherheit im Internet[1] [DIVSI], 2018). Asked whom they would turn to for expert knowledge about media-related questions, the respondents indicated that they would rely first on own and friends' experiences instead of asking teachers or parents for advice (DIVSI, 2018).

Since teachers play an important role in fostering the digital and media competencies of children and adolescents, it is important that universities prepare pre-service teachers for the upcoming challenges of digitization. To support the meaningfulness of the didactical and pedagogical realization of lessons with a focus on media competences, teachers and pre-service teachers need to have and develop pedagogical approaches in which such competences are centralized (Tulodziecki, 2012; Tulodziecki et al., 2021).

Different national and international media pedagogical and digital competency models have evolved over the last decades. Depending on origin and background, they differ in terms of

[1] German Institute for Trust and Security.

concepts, foci, and competency areas (see Tiede, 2020, for an overview). One prominent and widely cited framework in the discourse of media pedagogical competencies in teacher education is the technological pedagogical content knowledge (TPACK) framework (Mishra & Koehler, 2006), which can be adapted to different subjects. The popularity of this theoretical framework led to the publication of 2,202 TPACK-related works between 2005 and 2021 (Harris & Gallagher, 2021). Extending Lee Shulman's (1986) concept of pedagogical content knowledge (PCK), the TPACK model adds a further dimension to teachers' knowledge dimensions for effective teaching—namely, technology knowledge (TK). Regarding teachers' professionalization, TPACK relates to seven knowledge dimensions needed to plan and design media-integrated classes effectively (Mishra & Koehler, 2006). Along with pedagogical knowledge (PK) and content knowledge (CK) comes the necessity for teachers "to understand information technology broadly enough to apply it productively at work and in their everyday lives, to recognize when information technology can assist or impede the achievement of a goal, and to adapt continually to changes in information technology" (Koehler & Mishra, 2009, p. 64). However, given the rapid development of new technologies, continuous adaptation to change is challenging. Hence, understanding the processes underlying the use of technology in class goes beyond acquiring a dormant state of basic information technology (IT)-related knowledge. Rather, it includes providing teachers with the necessary strategies and supporting them to use new technology and to be self-determined in their planning and design of learning settings. Accordingly, Krauskopf et al. (2012) saw TPACK as a metaconceptual awareness comprising metacognitive learning processes involving higher order thinking.

Bertelsmann Stiftung's Digital Education Monitor indicated that pre-service teachers are not yet sufficiently prepared for the use of media in educational contexts (Schmid et al., 2017). Universities are better equipped with digital media than primary and secondary schools; however, technology implementation mainly occurs in teacher-centered teaching practices (Schmid et al., 2017). As a result, innovative learning formats for social and collaborative learning in higher education are lacking (Schmid et al., 2017). In addition, student teachers make less use of digital media than do their peers in other disciplines (Schmid et al., 2017). Although pre-service teachers use media in a private capacity to communicate with family and friends, they rarely use them for educational purposes (Schmid et al., 2017). In addition, Schmid et al.'s (2017) study showed that pre-service teachers are not media enthusiasts. Furthermore, fostering media pedagogical competencies is not yet an obligatory part of teacher education (Tiede & Grafe, 2016). Universities have to find new ways to engage pre-service teachers in using digital media for educational purposes so they will be prepared to use media in their future classrooms.

In higher education, institutions increasingly use web conferencing tools, such as Zoom or Microsoft Teams, for remote learning processes (Massner, 2021). Video-conferencing platforms support the communication and collaboration processes of teams with the help of digital features, such as breakout rooms, collaboration boards, and digital polls. Although transmitted via a two-dimensional (2D) desktop screen, these online communication and collaboration processes can create immediacy and social presence (Hacker et al., 2019, 2020). The perception of social presence, which is seen as one affordance of video-conferencing tools, can positively influence the co-construction of knowledge and thus benefit social learning processes (Cleveland-Innes & Garrison, 2020). However, 2D video-conferencing tools also impose certain constraints on social interactions in teams. In face-to-face conversations, speakers interpret and anticipate each other's verbal and nonverbal cues. Speakers tend to pay attention to their own verbal cues but focus rather on the nonverbal cues of their conversation partners (Bucy, 2017). In an in-person conversation, speakers process nonverbal information, such as facial expressions, body language, gaze, or eye contact, in under 100 milliseconds (Bucy, 2017). The unconscious processing of information creates an impression of a person's character and contributes to the formation of social judgment and trust or distrust (e.g., Dorairaj et al., 2012; Hambley et al., 2007; Hacker et al., 2019). This whole process happens spontaneously in face-to-face communication but takes more effort when video-conferencing systems are used (Hacker et al., 2019). Although video-conferencing systems are considered to have high synchronicity, Bucy (2017) found that there are severe delays of 135–487 milliseconds in speakers taking their turn. As a result, participants must handle the cognitive load of producing and interpreting the nonverbal cues of others.

Studies have theorized that alongside the increase in cognitive load, several nonverbal mechanisms may lead to the so-called Zoom fatigue that users have experienced after spending long hours in online Zoom meetings (Bailenson, 2021; Fauville et al., 2021). For example, self-focused attention is quite common because of a concentration on one's speaker window and representation in Zoom, leading to such possible adverse effects as anxiety or depression (Bailenson, 2021). Moreover, unlike in in-person meetings, people using Zoom try to stay in the field of view and unconsciously feel obliged to move within a certain radius (Bailenson, 2021). Consequently, users feel physically trapped and experience disruptive effects on cognitive performance (Bailenson, 2021). Because of the heightened cognitive efforts necessary to even out these disruptions in communication and collaboration, the capacity to devote cognitive processes to knowledge (co-)construction is limited, hindering effective group work and social learning processes (Bailenson, 2021).

A new way to overcome the problems described above in the use of video-conferencing systems while fostering pre-service teachers' TPACK may be the use of virtual reality (VR). VR offers experiences to users that come closer to real-life sensations than those offered by other technologies, enabling experiences that may even encroach on physical reality (Slater et al., 2020). Regarding education, this ability allows new ways of turning classrooms into explorative and interactive learning environments that enable the inclusion of content that would be too costly, abstract, dangerous, or in general, not feasible to explore with a class in real life. VR and immersive technologies, such as augmented reality (AR) and mixed reality (XR), are expected to become increasingly feasible as communication and interaction media in the future. Outside of entertainment, education will probably be the second sector after health care to be affected by the implementation of immersive technologies (Perkins Coie, 2020). As a special form of VR, social VR "is a web-based social interaction paradigm, mediated by immersive technologies and taking place in predesigned three-dimensional virtual worlds where individuals, represented by an avatar, may engage in real-time interpersonal conversation and shared activities" (Dzardanova et al., 2018, p. 1). Since VR is immersive in nature, users—represented by avatars—can experience the stimuli of their surroundings as if they were real and can interpret them as such; hence, their responses are similar to what they would be if interactions were initiated in the real world. For remote teaching and learning, in particular, the possibility of communicating and collaborating in real time and the feeling of being present in the virtual learning environment can be vital for social and situated learning processes.

From a theoretical perspective, the term VR has been interpreted in different ways (see Lou et al., 2021, for an overview). Furthermore, studies often lack a theoretical basis or target-oriented alignment with the pedagogical concept under consideration (Pellas et al., 2021). Thus, it is not easy to generalize about VR's affordances for teaching and learning processes. The rapid development of VR hardware and software, in particular, means that requirements for the integration of VR in educational contexts change dynamically.

In the empirical scientific discourse, there is disagreement on VR's potential for teaching and learning processes and its effects on learning outcomes. Whereas some studies have shown that VR has a rather distracting and cognitive-overloading nature in the context of learning settings (e.g., Parong & Mayer, 2021), others have confirmed VR's potential to motivate students to engage and perform in class and to create authentic learning environments (e.g., Liou & Chang, 2018; Southgate, 2020). Pellas et al.'s (2021) review emphasized that the successful implementation of VR in lesson designs is contextual and depends on various elements. Given the design, quality, and nature of the hardware and software, the main characteristics of VR can be either beneficial or disruptive to communication and collaboration processes—and thus, they can have related effects on learning processes. The degree of immersion, for example, varies among different kinds of VR systems. The immersion level depends on how the VR system represents the inclusive, extensive, surrounding, and vivid illusion of a virtual environment to the user (Slater & Wilbur, 1997). Immersion is the technical basis for the subjective sensation of being present in a virtual environment. The feeling of social presence, as the "perception of non-mediation" (Lombard et al., 2000, p. 77), refers to both artificial social actors (agents) and real social actors represented digitally in the virtual world.

Immersion and presence can make VR a valuable medium in education. As with any medium, however, merely integrating VR into teaching and learning does not guarantee additional value or improved learning success. It is essential to plan the implementation of the medium carefully and to consider several factors, such as prerequisites, requirements, and the process of iterative development, to ensure a successful and useful VR-supported learning process (Huang et al., 2010).

The use of VR in teacher education is gaining in importance. To date, observations in Virtual Learning scenarios have concentrated on the technical aspects of VR implementation (Dalgarno & Lee, 2010). Few studies have dealt with pedagogical aspects or have attempted to set standards for teaching and learning in VR. However, an example in initial teacher education (ITE) is the interdisciplinary project "Breaking Bad Behavior" (Lugrin et al., 2016). Using an action-oriented pedagogical approach in a fully immersive virtual classroom helped pre-service teachers develop their class management competencies (Seufert & Grafe, 2020; Seufert et al., 2022). Seufert and Grafe's (2020) study showed that the sound interplay of pedagogical concepts with the VR learning environment is important for the successful implementation of social VR and competency development.

Against this background, the aims of this dissertation are as follows: (a) to develop a pedagogical concept that promotes pre-service teachers' TPACK using a design-based research process and an iterative approach; (b) to investigate how social VR's attributes benefit or hinder learning processes; and (c) to map pre-service teachers' TPACK development to recommend future concepts in ITE. Hence, four studies are conducted with a view to answering the following research questions:

- What do student teachers and teacher educators expect of a successful virtual reality application in Initial Teacher Education (ITE?
- How do pre-service teachers perceive teaching and learning activities in social VR?
- How should a pedagogical concept for remote initial teacher education be designed to promote the metacognitive learning processes of pre-service teachers?
- How do pre-service teachers perceive these learning processes in video-based communication and social VR? How did pre-service teachers' TPACK develop using a social VR learning environment prototype compared to a video-conferencing system?

The remainder of this work is structured as described below.

In Chapter 2, the context is presented, and theoretical approaches and concepts are provided. First, Section 2.1 introduces TPACK (Mishra & Koehler, 2006), a prominent theoretical framework suggesting that teachers' successful technology implementation in class goes back to the combination of the three main knowledge domains—namely, PK, TK, and CK (Mishra & Koehler, 2006). Based on the interpretation of the TPACK model as metaconceptual awareness (Krauskopf et al., 2018), this section identifies pre-service teachers' requirements for knowledge acquisition in ITE. To meet the requirements, Section 2.2 outlines the potential affordances offered by social VR for teaching and learning processes from a theoretical perspective. For the design and development of a pedagogical concept that considers theoretical foundations and in-practice experiences, Section 2.3 describes the design-based research (DBR) approach. In particular, it focuses on Euler's (2011, 2014) basic structure model, which allows the iterative analysis, exploration, design, and development of the pedagogical concept. The circular structure of Euler's model also serves as a frame for the studies carried out for this research (Chapters three to five), which build on each other by using insights gained to further create and develop the pedagogical concept, leading to its evaluation in Chapter 6.

Chapter 3 analyzes teacher educators' and pre-service teachers' expectations of teaching and learning processes in social VR learning environments to answer the first research question. Following the call to combine scientific and practical perspectives, it identifies relevant theories and addresses existing practical conditions. To understand the requirements needed to plan and design a pedagogical concept and a social VR prototype for pre-service teachers and teacher educators, a qualitative interview method is used to provide the first design requirements and hypotheses for the design and development process.

Considering the in-practice experience of teacher educators and pre-service teachers, Chapter 4 investigates how pre-service teachers perceive the design features of social VR in changing learning scenarios. A guided interview method is used to prompt students to talk about their experiences in VR. The new insights gained lead to the revision and adaptation of the design hypotheses, which serve as a template for the further development of the prototypical pedagogical concept.

Following the design demand to promote TPACK and considering the affordances of social VR for learning, Chapter 5 introduces the approach of peer group supervision (Tietze, 2010). Apparently, the core elements of this approach allow learners to co-construct knowledge via reflection and peer feedback (Tietze, 2010). In line with the assumption that as a type of metaconceptual awareness, TPACK can be achieved via higher order thinking, such as reflecting and problem solving (Krauskopf et al., 2015; Krauskopf et al., 2018), peer support may afford metacognitive strategies to implement VR successfully. For the first test of the adopted design features, the study is undertaken in an authentic teaching–learning environment. A qualitative interview method is carried out to give insights into further improvements of the design measures of the pedagogical concept to allow metacognitive processes and to use the benefits of the social VR learning environment to promote learning processes.

Chapter 6 focuses on the implementation and evaluation of the pedagogical concept in an authentic practice context in ITE. Based on the results, assumptions can be made regarding design principles for the pedagogical concept to promote TPACK as a metaconceptual awareness in social VR.

Chapter 7 summarizes the findings of all four studies, presents the work's limitations, and outlines implications for further research and practice.

2. Context

2.1 Technological Pedagogical Content Knowledge

To be able to promote students' media competencies, during ITE, pre-service teachers must acquire the knowledge and skills required to effectively plan and design classes that integrate the use of media (see Chapter 1). Education research has shown that teaching and learning processes only benefit from technological affordances if certain conditions are met (Conole & Dyke, 2004). Authors have agreed on the complexity of properly implementing educational technology in pedagogical concepts (Foulger et al., 2017; Tondeur et al., 2019). Although there is little agreement on what is required for teachers to ensure successful media integration, teachers play a crucial role in this implementation process. Four main factors influence and predict the effective integration of information and communication technology (ICT) into teacher practice; these are as follows: (a) teacher knowledge, (b) teacher self-efficacy, (c) teacher beliefs, and (d) school/subject culture (Ertmer & Ottenbreit-Leftwich, 2010; Sang et al., 2011).

Various theoretical models, frameworks, and approaches have discussed which competencies are necessary to develop media integration in teacher education (see Tiede, (2020) for an overview). Reviews of competency frameworks have shown that various aspects differ in the theoretical approaches, such as the emphasis of media didactics in the models, the target group for the promotion of competencies, the underlying concept of "competencies" itself, and the overall composition of the competence models (see McGarr & McDonagh, 2019; Schmid & Petko, 2020; Tiede, 2020). As there is no common denominator, it is difficult to compare international frameworks without facing contextual bias. In her comparative analysis of international models, Tiede (2020) chose the generic term "media-related educational competencies," which allows international comparison.

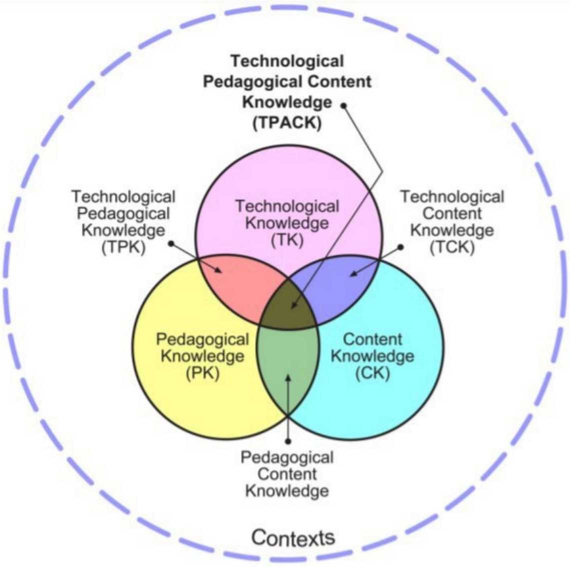
Three of the international models most prominently discussed in the literature are DigCompEdu (Redecker, 2017), UNESCO-ICT (UNESCO, 2018), and TPACK (Mishra & Koehler, 2006). Since the main objective of the current research is to promote the media-related educational competencies of pre-service teachers in a social VR learning environment, TPACK was considered an appropriate model for the following reasons: First, not only is it one of the most cited frameworks in the field of teacher professionalization, but it also has an empirical foundation. Second, it is particularly used in the context of ITE. Hence, the current research could build on the existing research of measurements and evaluations of pre-service teachers' TPACK.

TPACK is a theoretical framework built on the concept of PCK (Shulman, 1986, 1987). After a nationwide call for new reforms in teacher education in 1986, Shulman (1986) discussed the efforts made and pointed out possible weak points. According to the reform's supporters, an ever-growing knowledge base derived from research justified the implementation and extension of standards that enabled evaluation and examination processes in teacher education (Shulman, 1986). Shulman criticized the superficial consideration of the term "knowledge base" and elaborated on the knowledge needed for a "novice teacher" to become an "expert" one (1986, p. 6). Expert teachers not only transmit CK to students but can also articulate why a particular statement is considered justified, why pupils might need this knowledge, and how it relates to other contexts (Shulman, 1986). It is not enough to acquire CK to develop the ability to teach in this way. Shulman (1987) recognized PCK as one vital source of knowledge that "identifies the distinctive bodies of knowledge for teaching" and "represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (p. 9). With the ever-growing need to prepare pre- and in-service teachers for technology integration in educational contexts, several works have built on the notion of PCK and developed approaches to integrating technological knowledge (TK) into Shulman's PCK concept (see Mishra & Koehler, 2006; Niess, 2005; Pierson, 2001). For example, Pierson (2001) suggested adding TK to PK, CK, and PCK. Beyond the first two intersections, which Pierson labeled A (knowledge of content-related technology resources) and B (knowledge of content-related technology resources), the third intersection represents C, TPCK (combining TK, PK, and CK). According to Pierson (2001), TPCK comprises knowledge of "true technology integration" (p. 427). Inherent to all approaches adding TK to the PCK model is the assumption that teaching effectively with technology results from the dynamic interplay of PK, TK, and CK rather than from treating knowledge bases as isolated knowledge bodies.

One of the most prominent approaches is the theoretical framework of TPACK developed by Koehler and Koehler (2005, 2006, 2007, 2008, 2009); these researchers coined the term TPCK, which later evolved into TPACK. Noting that modern technologies develop rapidly and lack adjustability to educational contexts, the authors emphasized the necessity for pre-service teachers to prepare for effective technology integration in the classroom. For this, they need to acquire TPACK.

Figure 1

TPACK Venn diagram (Koehler & Mishra, 2009)



As displayed in the Venn diagram in Figure 1, there are three knowledge domains at the core of the model—namely, PK, CK, and TK (Koehler & Mishra, 2009). Four more knowledge areas—technological pedagogical knowledge (TPK), technological content knowledge (TCK), PCK, and TPACK, represent the intersections of the three primary knowledge domains (Koehler & Mishra, 2009).

The individual knowledge domains can be described in more detail as follows:

- **CK** is knowledge about the subject matter (Koehler & Mishra, 2009). Derived from Shulman's (1986) notion of CK, it comprises "the knowledge of theories, concepts, ideas, organizational frameworks, knowledge of evidence and proof, and practices and approaches to develop such knowledge" (Koehler & Mishra, 2009, p. 63).
- **PK** is knowledge about teaching and learning processes (Koehler & Mishra, 2009). In addition, it involves understanding students' learning processes, planning and designing classes, and classroom management skills (Koehler & Mishra, 2009).
- In line with Shulman (1986), **PCK** refers to knowledge of how to teach a particular subject (Koehler & Mishra, 2009). Going beyond the mere transfer of knowledge, PCK includes processes connected to the representation of content, such as designing the teaching and learning process in a way that is conducive to learning (Koehler & Mishra, 2009). According to the authors PCK "covers the core business of teaching, learning, curriculum, assessment and reporting, such as the conditions that promote learning and the links among curriculum, assessment, and pedagogy" (p. 64).

- **TK** goes beyond technical usage and includes the teacher's knowledge of how the technology supports or drives processes in a target-oriented manner (Koehler & Mishra, 2009). This requires profound knowledge about a technology's characteristics, affordances, and application scenarios (Koehler & Mishra, 2009). Moreover, given the rapid development and innovation of technology, this knowledge needs to adapt to current conditions flexibly and should thus involve various strategies (Koehler & Mishra, 2009).
- **TCK** refers to the fruitful combination of TK and CK (Koehler & Mishra, 2008, 2009). It represents teachers' knowledge of the various ways in which a technology can be used to deliver content (Koehler & Mishra, 2009). In particular, it involves knowledge of how the subject matter influences how a technology is applied (Koehler & Mishra, 2009).
- **TPK** involves the goal-oriented adaptation of technology to teaching and learning processes (Koehler & Mishra, 2009). In addition to a deep knowledge of the functionalities of technology's features and how to use them in pedagogical contexts, TPK "requires a forward-looking, creative, and open-minded seeking of technology use" (Koehler & Mishra, 2009, p. 66).
- **TPACK** represents the interplay of all the knowledge components above (Koehler & Mishra, 2009). The authors distinguish TPACK as a "unique body of knowledge" that requires "teachers' cognitive flexibility not just in each of the key domains, but also in the manner in which these domains and contextual parameters interrelate" (Koehler & Mishra, 2009, p. 66).

Mishra and Koehler (2006) also emphasize the importance of binding contextual factors, such as school infrastructure and learners' background. In 2019, Mishra labeled the outer circle line in the model as "Contextual Knowledge" (see Figure 1); this includes the teacher's awareness of the external factors influencing the teaching and learning processes, such as the availability of existing resources and regulations.

TPACK has gained wide recognition and prominence both nationally and internationally. Indeed, more than 1,418 journal articles, 318 chapters, 28 books, and 438 dissertations referring to TPACK have been published to date (Harris & Gallagher, 2021). Literature reviews (e.g., Irwanto, 2021; Wang et al., 2018; Willermark, 2017) have confirmed that most studies referring to TPACK are from North America; nevertheless, publications are increasingly emerging from other countries (Irwanto, 2021). The main topics on which works have focused are as follows: (a) whether TPACK is by nature integrative or transformative (Angeli & Valanides, 2013; Chai et al., 2010), (b) whether TPACK is domain-generic or domain-specific knowledge (Guzey & Roehrig, 2009; Lin et al., 2013), (c) the composition and interplay of the knowledge domains (Archambault & Barnett, 2010), (d) methods leading to TPACK (Harvey & Caro, 2017; Tseng et al., 2019), (e) possible extensions of TPACK (Porras-Hernández & Salinas-Amescua, 2013; Urban et al., 2018), and (f) how to measure and develop TPACK (Graham et al., 2012; Harris & Hofer, 2009). In this work, TPACK has the following attributes: (a) it serves as a target for pre-service teachers' learning processes, and accordingly, (b) it guides the iterative design and evaluation of the pedagogical concept.

The requirements for TPACK are diverse and complex (see Chapters 5 and 6 for more detail). Koehler and Mishra (2009) have emphasized the "dynamic" (p. 61) nature of the knowledge domains and their respective context. On the one hand, this dynamic nature comes from the different existing external and internal conditions pre-service teachers have to face at schools, and on the other, it stems from the continuous rapid development of technologies and their associated diverse sets of affordances for the teaching and learning processes (see Section 2.2). Thus, to go beyond a fixed body of knowledge that can be acquired, pre-service teachers need metacognitive strategies that involve higher order thinking skills (Krauskopf et al., 2015; Krauskopf et al., 2018). Such skills enable them to analyze, evaluate, and reflect on how technologies can be used in a target-oriented way to promote competencies in different contexts (Krauskopf et al., 2015; Krauskopf et al., 2018). The more pre-service teachers experience these strategies during their teacher education, the higher their perceived competence to use ICT for learning processes and to strengthen their instructional practice (Tondeur, 2018). In this work, TPACK acquisition is considered a dynamic learning approach that involves metacognitive learning processes (Krauskopf et al., 2015; Krauskopf et al., 2018). Krauskopf et al. (2018) built on the transformative view of TPACK and defined it as a

> coherent scientific framework theory [that] is (1) a unitary shape with a clear application context (teaching with technology), (2) the assumption of a limited number of pre-suppositions about technology, pedagogy and content (ontological and epistemological) that constrain the construction of more specific theories (mental models) derived from them, (3) the idea of a meta-conceptual frame for the systematic relations of these presuppositions and the teacher's knowledge of the sub-domains. (p. 22)

These authors assumed that TPACK is achievable through a two-level process of constructing mental models (Krauskopf et al., 2018). The knowledge subdomains (TPK, PCK, TCK) translate to mental models on the first level. According to the authors, mental models are constructed through reflection on theory and considering others' teaching practice (Krauskopf et al., 2018). Thus, the second-level transformation results in the "higher mental model" of TPACK, which involves the meta-awareness of effectively implementing technology in teaching and learning processes (Krauskopf et al., 2015, pp. 4–5). This complex transformation process poses a challenge for the pedagogical concept of designing respective learning activities, allowing the construction of TPACK as metaconceptual awareness.

2.2 Social Virtual Reality's Affordances for Teaching and Learning Processes

Since social VR offers potential for fostering teaching and learning processes in ITE (see Chapter 1), this section focuses on the terminology and concepts concerning the VR learning environment and its affordances for teaching and learning scenarios.

With regard to the term "social VR," various interpretations of VR exist in the literature (e.g., Hamilton et al., 2020; Radianti et al., 2020; Riegler et al., 2021). In the current research, as initially stated, the definition of social VR proposed by Dzardanova et al. (2018) is used as a basis because it emphasizes the affordance of VR to allow social interactions between participants: "Social Virtual Reality is a web-based social interaction paradigm, mediated by immersive technologies and taking place in predesigned three-dimensional virtual worlds where individuals, represented by an avatar, may engage in real-time interpersonal conversation and shared activities." (p. 1)

Immersive technologies can refer either to semi-immersive systems, representing a combination of 2D and immersive extensions, or to highly immersive systems (Hamilton et al., 2020). In this research, the social VR learning environment ViLeArn (Latoschik et al., 2019) is used, which is a highly immersive system (for a description see Chapters 4-6).

Social VR is a research topic in many scientific disciplines, including human–computer interaction, medicine, education, and healthcare; the affordances for teaching and learning scenarios in social VR vary among these disciplines. Many interpretations of the concept of affordances can be traced back to two main strands. From the ecological perspective, the perceptual psychologist Gibson (1979) described affordances as follows: "The affordances of the environment are what it *offers* the animal, what it *provides* or *furnishes*, either for good or ill. … It implies the complementarity of the animal and the environment" (p. 127, Gibson's italics). Investigating what the affordances of nature provide for the environment and its creatures, Gibson (1979) assumed that particular objects stimulate their surroundings to enable them to take possible actions. Hence, he used the term *affordance* to refer to the relationship between an object and an agent. Gibson's (1979) concept of affordance implies that living beings perceive the objects in their environment against the background of their bodies and the resulting corresponding possibilities of action that an object offers. Thus, the affordance of an object is independent of the needs, attention, or evaluation of an observer (see Guski, 1996). For example, a chair "affords" sitting, regardless of whether someone wants to sit on it (Guski, 1996, p. 5).

Norman (1988) introduced another popular definition of *affordance* connected to the design of interfaces and their usability, mainly used in the field of Human Computer Interaction (HCI):

> [...] the term *affordance* refers to the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used. [...] Affordances provide strong clues to the operations of things. Plates are for pushing. Knobs are for turning. Slots are for inserting things into. Balls are for throwing or bouncing. When affordances are taken advantage of, the user knows what to do just by looking: no picture, label, or instruction needed. (Norman 1988, p.9)

In Norman's (1988) definition, the concept of affordance also comprises the user's perception, and it goes beyond the relationship between object and agent. In this sense, an affordance is a visible design aspect of an object (McGrenere & Ho, 2000). In contrast to Gibson (1979), who defined an affordance as the offering character of an object's utility, Norman (1988) focused on the user's perception of the visible design characteristics of an object as its usability.

In the discourse of affordances for social VR in education, several authors refer to Bower's (Bower, 2008; Bower & Sturman, 2015) term "learning affordances" (e.g., Dalgarno & Lee, 2010; Southgate, 2020). Bower built on both, Gibson's (1979) and Norman's (1988) use of affordances. Rather than evaluating technologies' effects on the user, he cited Gibson (1979) when investigating the potential of possible technologies for the design of learning tasks. Thus, Bower (2008) also emphasized the detachment of the object's affordance from any context such that it "avoids any contextual biases that could be caused by the experience or culture of the user" (p. 5). In contrast, when evaluating users' perceptions of affordances, Bower and Sturman (2015) followed the perceived usability aspect of technologies' affordances and based their work on Norman's (1988) definition. They concluded that "if the use is there but not perceived, then it is of no educational benefit" (Bower & Sturman, 2015, p. 345). Bower's (2008; Bower & Sturman, 2015) approach to the use of the term *affordance*—that is, that it depends on the respective research focus—is employed in the current research throughout the DBR cycle. In terms of analyzing and exploring social VR's potential for teaching and learning processes in ITE, *affordances* serves as a generic term in this work (see Chapters 3 and 4) in the sense put forward by Gibson (1979) and Bower (2008). These affordances, derived objectively for the design of teaching and learning activities, are considered separately from users' perceptions and cultural context (Bower, 2008; Gibson, 1979). However, when the focus is on the evaluation of pre-service teachers' perception of social VR's use in teaching and learning activities, the term *affordances* is used in the sense put forward by Norman (1988) (Bower & Sturman, 2015). Here, the implementation and design testing of the pedagogical concept is inseparable from the perceived affordances of the social VR learning environment (see Chapters 6 and 7).

Against the background delineated above, three of social VR's affordances are central to the design of teaching and learning activities in this work; these are immersion, presence, and embodiment. The concept of immersion refers to the mere technical properties a social VR system offers that can be objectively assessed (Kilteni et al., 2012; Slater & Sanchez-Vives, 2016; Slater & Wilbur, 1997). The degree of experienced immersion depends on the technical characteristics transmitting the "illusion of reality" in a way as vivid, extensive, encompassing, and inclusive as possible (Slater & Wilbur, 1997, p. 3). *Presence* differs from *immersion* in that it is a psychological construct representing the "human reaction to immersion," leading to the "sense of being there" in the virtual environment (Slater & Wilbur, 1997, pp. 4–5). Based on the subjective perceptions of place and plausible illusions, users interpret their surroundings as realistic stimuli, leading to actions being carried out as they would be in the "real world" (Slater & Wilbur, 1997, p. 5). Embodiment results from the illusion of ownership of the virtual body and leads to the feeling of being able to carry out certain actions with gestures or movements, which are closely related to the construct of agency (Johnson-Glenberg, 2018).

In comparison with other educational technologies, affordances are unique features that benefit multimodal, adaptive, authentic, and interactive learning scenarios. Dalgarno and Lee (2010, pp. 18–21) saw the affordances of three-dimensional (3D) virtual environments in the facilitation of tasks that have the following characteristics:

- They lead to the development of enhanced spatial knowledge representation of the explored domain.
- They would be impractical or impossible to undertake in the real world.
- They foster increased intrinsic motivation and engagement.
- They lead to improved transfer of knowledge and skills to real situations through contextualization of learning.
- They allow richer and/or more effective collaborative learning than is possible with 2D alternatives (Dalgarno & Lee, 2010, pp. 18–21).

Similarly, Hellriegel and Čubela (2018) took Arnold's (2012) principles for successful learning as the basis of the potential of VR for the following elements: (a) learning as a self-directed, activating, and constructive process; (b) learning as a motivating process; (c) learning as a situated and hands-on process; and (d) learning as a social process. With the objective of developing a pedagogical concept to promote the TPACK of pre-service teachers, the current research implements social VR's affordances in teaching and learning processes in ITE (see Chapters 3 to 6).

2.3 Design-Based Research

The promotion of TPACK in a social VR learning environment represents a desideratum in research. Therefore, to generate insights for practice and further develop theory building to promote TPACK in this context, the DBR approach is a suitable framework.

Although the term *DBR* was coined by the Design-Based Research Collective (2003), it has received different accentuations in the literature from various perspectives. Over the past 20 years, DBR has become an established research approach in Anglo-American educational research, blending empirical educational research with the theory-driven design of learning environments. Plomp (2010) defined DBR as follows:

> The systematic study of designing, developing and evaluating educational interventions (such as programs, teaching-learning strategies and materials, products and systems) as solutions for complex problems in educational practice, which also aims at advancing our knowledge about the characteristics of these interventions and the processes of designing and developing it. (p. 13)

In response to the existing gap between educational research on innovation and its relevance for actual in-practice teaching and learning scenarios, several concepts have emerged with the objective of focusing on the development and design of educational processes. In comparison with experimental or evaluation research, the new approaches do not treat design and research as two consecutive steps in the research process; rather, the design becomes the source for the development of theories (Euler, 2014). Under the umbrella term of “design research,” Euler (2014) pointed to existing variations of the approach, such as “design-experiments” (Brown, 1992), “development research” (Van den Akker, 1999), “formative research” (Newman, 1990), and “educational design research” (McKenney & Reeves, 2012). Instead of speaking of a methodology, some authors (see Euler, 2011; McKenney & Reeves, 2013; Raatz, 2016) have agreed that design research is more like a frame for existing research methods (quantitative, qualitative, or mixed methods) than an inherently “new” method.

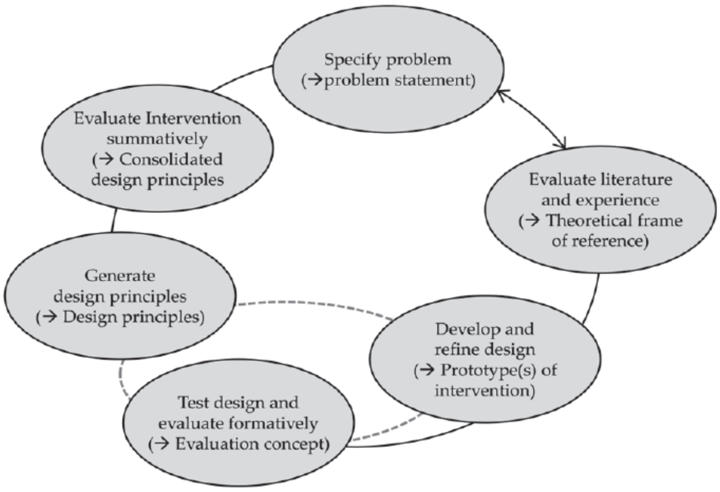
In line with the developments outlined above, German-speaking authors adopting the DBR perspective in media education have also emphasized the need to develop and design educational processes, including innovative media. Tulodziecki et al. (2018), following the action-oriented approach in media education, referred to the DBR method as an “accentuation” (p. 436) of design and development-oriented research. The authors differentiated action research (e.g., Altrichter & Posch, 2007), integrative research strategies (e.g., Brown, 1992), didactical development research (e.g., Einsiedler, 2010), and the practice- and theory-oriented development and evaluation of concepts for educational action (e.g., Tulodziecki, 1983), as well as the concept of development-oriented educational research (e.g., Reinmann & Sesink, 2011), as further variations of this line of research. All these approaches, including DBR, vary in some respects; however, at their core, they share the intention of improving the scientific foundation of action in practice and in educational processes (Tulodziecki et al., 2018).

The main characteristics of DBR are using an iterative and circular approach to develop solutions to problems, the theory-driven anchoring of the research and design process, the integrative use of research methods, and the continuous interplay of science and practice (see Euler, 2011; McKenney & Reeves, 2012; Raatz, 2016; Reinmann & Sesink, 2011; Tulodziecki et al., 2013). To derive implications for in-practice implementation, Euler (2014) reviewed the most prominent DBR process models (Anderson & Shattuck, 2012; Bannan-Ritland, 2003; McKenney & Reeves, 2013; Reeves, 2006), and based on their shared features, he developed a basic structure model. Then, “to develop a paradigm-constitutive normative structure for the scientific community of design researchers by providing the foundation and the justification of the guidelines” (Euler, 2014, p. 22), he outlined each step of the model, explaining the *core requirements*, the *core questions and guidelines*, and what *result* is expected at the end of each process.

Along with the *iterative and circular structure* of Euler’s (2014) process model, the main features of the DBR approach mentioned above require further consideration.

Figure 2

Research and development cycles in the design research context



The starting point of the research and development cycles is the specification of the problem at hand. With the goal “to identify the (key) objectives related to research and design issues” (Euler, 2014, p. 25), a precise analysis of the factors connected to the problem is necessary to lay the ground for subsequent procedures. However, it is insufficient to consider only the contextual factors connected to the problem observed in practice when it comes to specifying the problem. Moreover, for a holistic analysis, scientific theories must underpin practical knowledge. Therefore, the analysis follows a theory-driven derivation of possible design hypotheses, constructing a “theoretical frame of reference” (Euler, 2014, p. 26) that comprises problem statements, design requirements, and possible solutions. Multiple (iterative) cycles of development, testing, evaluation, and refinement of the design follow. Systematic documentation of the development process is necessary to comprehend the acquisition process of knowledge.

In the context outlined above, the *theory-driven anchoring of the research and design process* plays a twofold role throughout the procedure. Although on the one hand, theory serves as a foundation for the derivation of the conceptual framework, on the other, it allows conclusions to be drawn for the further development, redefining, and evaluation cycle of the underlying design principles. Thus, theory application, verification, and development are interconnected (Euler, 2014).

Concerning *the integrative use of research methods*, following McKenney and Reeves (2012), Euler (2014) differentiated between the foci of various evaluations (alpha, beta, and gamma testing) throughout the development stages, hand in hand with corresponding evaluation strategies and methods. As possible evaluation strategies, he outlined the four following procedures: (a) discussion and screening of the intervention with focus groups, checklists, and document analysis; (b) approaching external experts; (c) conducting a pilot test with a small sample; and (d) a tryout in the actual situation. He particularly emphasized the importance of the acquisition and analysis of qualitative data to gain a holistic perspective on the contextual factors involved (Euler, 2014).

Throughout all phases of the process model, the *interplay of science and practice* is essential for the implementation of design in its application context (Euler, 2014). Incorporating practitioners into the research and development cycles enables the evolution of practical problem-solving approaches that can be transferred to real application scenarios (Euler, 2014). Further, with the help of practitioners' knowledge, interventions can be designed in a more objective and effective way, avoiding unnecessary detours for knowledge generation (Euler, 2014). However, Euler (2014) also warned that scientists' "critically evaluative attitude" and practitioners' "design-oriented and decision-oriented position" (p. 27) may diverge throughout the research and development process.

Euler's process model provides a suitable framing for the research process of the current work. Since the objective is to promote pre-service teachers' TPACK in a fully immersive learning environment, numerous contextual factors must be considered throughout the research process. Because of the desideratum in research, it is not clear what these contextual factors comprise. The two focuses on TPACK as a metaconceptual awareness and social VR for teaching and learning processes represent complex reference frames that are only complementary under certain conditions. Further, in the context of ITE, there are rarely best practices or hands-on experiences. However, to ensure that the designed pedagogical concept and social VR learning environment are suitable for in-practice implementation and knowledge generation, the close interplay of science and practice is crucial. Since the technical development of the social VR learning environment goes hand in hand with educational design, the interdisciplinary exchange between scientists and practitioners is all the more important for effective teaching–learning processes. Euler's (2014) model emphasizes both perspectives at each stage of the research and development cycle. Dismantling the complexity of this multi-layered research interest, Euler's (2014) three-part orientation starts with the core requirements, moves to core questions, and concludes with the expected results of each stage. Thus, the model offers a template that entails guided practices, allowing the design of a pedagogical concept for social VR that finds its way into in-practice implementation and knowledge acquisition beyond the research process.

3. Teaching and Learning Processes in Immersive VR – Comparing Expectations of Pre-service Teachers and Teacher Educators

3.1 Aims of Study 1

As per the first and second stages of Euler's (2014) process model, Study 1 specified a given problem as the starting point for the research and development cycles and evaluated the literature and experience (Section 3.2). The problem statement of this work was derived from two lacks in ITE. First, pre-service teachers lack media-related educational competencies and need the promotion of TPACK (see Foulger et al., 2017, Voogt et al., 2013). Second, there is a lack of innovative pedagogical concepts integrating social VR to promote TPACK in ITE (see Foulger et al. 2017, Tondeur et al., 2019). Consequently, pedagogical concepts for ITE are needed that promote pre-service teachers' TPACK, which is addressed in the current research. To ensure the practicability of the pedagogical concept for in-seminar implementation, an intervention must consider the close interplay of science and in-practice experiences (see Euler, 2014; Raatz, 2016). When reviewing literature and hands-on experiences, most works have focused on the technical perspective of VR implementation (e.g., Pellas et al., 2021; Radianti et al., 2020). For the successful implementation of fully immersive VR in practice, however, pedagogical factors play a crucial role (Huang et al., 2010). Hence, the theory-based design principles of a pedagogical concept and the in-practice experience of practitioners have to be considered. Teacher educators' and pre-service teachers' attitudes and beliefs about a given technology are indicators of successful future interaction with the medium in their teaching practice (Blömeke, 2017; Ertmer & Ottenbreit-Leftwich, 2010; Sang et al., 2011). Accordingly, the first study in this work (Section 3.2.) addressed the first research question:

- What do student teachers and teacher educators expect of a successful virtual reality application in ITE?

The results allowed us to derive the first requirements for the design of the pedagogical concept and an intervention as well as to extend the problem statement (Euler, 2014).

3.2 Study 1

SITE 2020 - Online, , April 7-10, 2020

Teaching and Learning Processes in Immersive VR – Comparing Expectations of Preservice Teachers and Teacher Educators

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Abstract: The usage of VR in higher education is not uncommon anymore. However, concepts are mainly still focusing on technical rather than pedagogical aspects of VR in the classroom. The exploration of the expectations of teacher educators as well as of preservice teachers appears indispensable (1) to achieve a sound understanding of requirements, (2) to identify potential design spaces, and finally (3) to create and to derive suitable pedagogical approaches for VR in initial teacher education. This paper presents results of guideline-based qualitative interviews comparing the expectations of teacher educators and of preservice teachers regarding teaching and learning in immersive virtual learning environments. The results showed that preservice teachers and teacher educators expect VR to enrich classes through interactive engagement in situations that would otherwise be too costly or dangerous. Regarding the design, teacher educators put the emphasis on functionality. Student teachers emphasized that they do not want to miss social interactions with their peers. Furthermore, both groups stated preferred modes of collaboration and interaction taking into account the characteristics of a virtual learning surrounding such as being able to use diverse learning spaces for group work. Interviewees agreed on two vital factors for effective learning and teaching processes: flexibility and the possibility of customization considering technical properties that are to deal with. Apart from this, preservice teachers emphasized strongly their worries about data usage and the ethics regarding using avatars and agents for representation.

Keywords: initial teacher education, virtual reality, teacher education, educational technology, competency-based teaching, media pedagogical competencies

Introduction

The increased need to use digital media in classrooms induces a modification of the requirements and demands regarding teaching competencies. These competencies also have to cover a responsible and efficient media usage (e.g. KMK, 2016; U.S. Department of Education, Office of Educational Technology, 2016). The need to acquire such media pedagogical competencies for the beneficial pedagogical use of new technology in the classroom is comprehensive. It turns-up for most groups and stages in the teaching system, e.g., for preservice teachers as well as for teacher educators (Herring, Thomas, & Redmond, 2014). As a consequence, learning scenarios at universities need to integrate innovative concepts that promote the usage and reflection of digital media in initial teacher education (Borthwick & Hansen, 2017).

Media such as VR can offer a promising potential for fostering media pedagogical competencies in initial teacher education programs. Yet, as with any medium, the sheer integration of VR in teaching and learning does not guarantee an additional value or improved learning success. A growing number of research works confirms its affordances (Latoschik et al., 2019) and suggests additional values when it is included into educational settings reasonably (e.g. Lamb, Hand, Etopio, & Yoon, 2019). It is essential to plan the implementation of the medium carefully and to consider several factors such as prerequisites and requirements, but also the process of iterative development to ensure successful and useful learning processes supported by VR (Huang, Rauch, & Liaw, 2010). So far studies have dealt with either the students' or the teachers' perspective. Seldom both views are taken into account (Radianti, Majchrzak, Fromm, & Wohlgenannt, 2018).

Against this background, this study, as the preliminary work of an iterative research process, seeks answers from both teacher educators as well as preservice teachers for the question: What do student teachers and teacher educators expect of a successful virtual reality application in Initial Teacher Education (ITE)? This research question is highly relevant as the design and use of Virtual Reality (VR) in the curriculum of initial teacher education as a learning and teaching tool is gaining in importance in higher education (Adams et al., 2017).

Implementing VR in Initial Teacher Education

Focusing on post-secondary Education, Concannon, Esmail and Roberts (2019) found that VR has mainly been implemented in educational disciplines like Science and Tech as well as Health Sciences. Regarding the pedagogical perspective, works miss setting standards for teaching and learning in VR (Fowler, 2014).

As the main focus of this study deals with learning and teaching processes, central components that are linked to them have to be taken into account: These include (1) learning prerequisites, (2) learning objectives, (3) teaching and learning activities, technology and social forms (Tulodziecki, Herzig, & Grafe 2019). These criteria will be used to systematize the following literature review adopting both perspectives, i.e., the teacher educators' and the students'.

Regarding the learning prerequisites, teacher educators often do not have sufficient knowledge, skills and competencies of how to use VR in seminars (Goktas, Yildirim, & Yildirim, 2009; Uerz, Volman, & Krai, 2018). They need continuous professional development to be able to foster preservice teachers' competencies in using digital media pedagogically in the classroom (Voogt, Fisser, Pareja Roblin, Tondeur, & van Braak, 2013; Foulger, Graziano, Schmidt-Crawford, & Slykhuis, 2017), for example in the form of further training courses. However, as research and practice of using immersive VR technology in teacher education is scarce, but expanding (Billingsley, Smith, Smith, & Merrit, 2019), at some departments teacher educators with rich experiences can be found, too. They are a rich source for learning about expectations on how to implement immersive VR successfully in teacher education programs and will be addressed in this study. With regard to preservice students it can be stated, that they see the advantages of implementing VR in the classroom, but they lack self-efficacy to use it themselves (Browne & Cooper, 2000).

With regard to learning objectives in teacher education, the demand for digital competencies increases with the rise of new technologies, such as VR (Borthwick & Hansen, 2017). Since preservice teachers have to be prepared for the pedagogical integration of media in class, also their educators should acquire the corresponding knowledge (Kay, 2006; U.S. Department of Education, Office of Educational Technology, 2017). Preservice teachers' and teacher educators' requirements differ in regard to the way of acquiring and fostering media pedagogical competencies (Krumsvik, 2014). Models addressing preservice teachers' and teacher educators' competency acquisition may serve as a theoretical basis for defining learning objectives for using fully immersive VR in teacher education. With regard to (student) teachers' competencies the Technological Pedagogical Content Knowledge Framework [TPACK] (Mishra & Koehler, 2006), the Digital Competence Framework for Educators [DigCompEdu] (Redecker, 2017), the UNESCO ICT Competency Framework for Teachers (UNESCO, 2018) and the Media Pedagogical Competencies Model [M³K] (Herzig, Martin, Schaper, & Ossenschmidt, 2015; Tiede & Grafe, 2016) can serve as systematic frameworks. With reference to teacher educators' competencies the Teacher Educator Technology Competencies [TETCs] framework (Foulger, Graziano, Schmidt-Crawford, & Slykhuis, 2017) and the Media Literacy Reference Framework for learners, teachers and teacher educators [Media Didactica] (Meeus, Van Ouytsel, Driesen, & T'Sas, 2014) are the only frameworks which address teacher educators as a target group explicitly. However, the authors of the DigCompEdu Framework claim to cover educators of all stages (Redecker, 2017). For the use of VR in teacher education learning objectives which address teaching and learning in fully immersive VR explicitly have to be derived from these frameworks.

Having dealt with the learner's prerequisites and their learning objectives, the question arises how learning and teaching processes using different social forms can beneficially be influenced by the technology of fully immersive VR. To answer this question, firstly the technical main characteristic that distinguishes fully immersive VR from other VR systems, such as desktop-based VR, has to be mentioned. Fully immersive VR can be described by Biocca's and Delaney's (1995) definition of VR as ''the sum of the hardware and software systems that seek to perfect an all-inclusive, sensory illusion of being present in another environment'' (pp. 57- 124). A recent article by Skarbez et al. (2017) includes an up-to-date discussion of immersion and presence. They propose a model that distinguishes between different qualia of VR systems, i.e., presence being composed of and affected by the social presence, plausibility, and place illusions, where the place illusion is a function of immersion as an objective characteristic of a virtual experience. The multi-sensory experience of VR leads to the brain's interpretation of the virtual stimuli as real world's stimuli (Kilteni et al., 2015). The resulting full immersion of the user into another world that pretends to be real brings with it the possibility for educators to create learning scenarios that otherwise would be difficult or impossible to integrate into the real world classroom (Grenier et al., 2015). To benefit from its nature, in higher education, fully immersive VR has mainly been implemented for the purpose of training skills (e.g. Moro et al., 2017) or promoting interactivity (e.g. Lamb et al. 2018). In their literature review Radianti et al. (2019) found that 68% of works with VR implemented in higher education did not state the underlying learning theories such as cognitivism (cf. Dede, 2009) or constructivism (cf. Sharma, Agada, & Ruffin, 2013). Also, very few authors give explicit suggestions or best practices regarding learning and teaching processes in fully immersive learning environments. Huang, Rauch and Liaw (2018) for example suggest, in their case study about learners' attitudes towards VR, to use the advantages of the immersive nature of VR with the help of a constructivist learning approach. Starting from the understanding of learning processes in virtual learning environments that is based upon elementary aspects of a constructivist learning theory (cf. Shih & Yang, 2008) the authors propose theory-guided five learning strategies for instructional designers: (1) Situated learning, (2) Role playing, (3) Cooperative/ collaborative learning, (4) Problem-based learning and (5) Creative learning. These derive from combining constructivist's elements with fundamental features of VR, such as immersion, interaction and imagination (cf. Burdea & Coiffet, 2013). The practical implementation and the effects of the learning strategies on the learning outcomes, however, have not been researched so far and still represent a desideratum in literature. In general, works focus on either the technical or pedagogical characteristics of VR. Radianti et al. (2019) suggest for future research to complement technology with pedagogy and vice versa as well as to combine the teachers' and students' perspectives. So far, works concentrated on one target group led to a one-sided evaluation (*ibid.*).

Interview Research Methodology

To systematically explore the requirements of preservice teachers and teacher educators an analysis of needs was conducted with the two target groups using guideline-based qualitative interviews (Przyborski & Wohlrab-Sahr, 2014). The central components of teaching and learning with technology (Tulodziecki et al., 2019) served as an orientation for the development of the guideline-based interviews. Furthermore, it was important to achieve a sound understanding of technical requirements for the VR system to identify potential design spaces. In addition, it was necessary to investigate possible pedagogical and technical forms of support for the successful implementation of VR in Initial Teacher Education:

1) Prior experiences of preservice teachers and teacher educators with VR;
2) Assumptions about potential teaching and learning scenarios in VR to achieve different goals in initial teacher education;
3) Assumptions about the characteristics of these teaching and learning scenarios in VR in initial teacher education;
4) Technical requirements for the VR system itself but also for the ways of communicating in a virtual environment; and
5) Support, technically and pedagogically, that both groups might need to use VR in class

The interviews were conducted with two convenience samples of $n_1 = 12$ preservice teachers and $n_2 = 10$ teacher educators from a university in Germany. The target groups were chosen intentionally from the same department as both groups experience the same pedagogical implementation of digital media in seminars.

The preservice teachers and the teacher educators were expected to have different levels of experiences regarding the use of VR in their leisure time and in teacher education. Based on the specific focus on digital media and VR in teacher education of this department, however, the prior experience of teacher educators with and exposure to digital media and VR in particular can be expected to be richer than the average of other German institutions. As mentioned above, they are a helpful source for learning about expectations on how to implement immersive VR successfully in teacher education. The varied expectations based on their differing experiences of teacher educators and student teachers in the sample is considered to be very valuable to get a holistic image of the combination of technical and pedagogical aspects involved in ongoing teaching and learning processes.

To be able to compare the perspectives of teacher educators and student teachers, the two interview guidelines for student teachers and teacher educators were designed widely congruently. Both guidelines share the same main categories but vary in elements because of the differing characteristics considering the nature of a teacher's and learner's role. For example, teacher educators were asked about possible scenarios for further education concepts while student teachers' interview focused on full seminars. Each person of both groups was interviewed individually for the duration of an hour. Participants were contacted via email and chose to participate voluntarily. Due to organizational reasons, the teacher educators had to be interviewed via an online video call, while student teachers were interviewed in person. However, the interview procedure was identical to minimize possible differences between the online interview and the face-to-face interview.

The interviews were recorded, transcribed and analyzed by means of qualitative content analysis (Mayring, 2015). They were all coded using MAXQDA (Rädiker & Kuckartz, 2019). The following categories were determined deductively in advance, based on the shared main foci of the two interview guidelines and following the approach of Mayring (2015):

1. Experiences with VR
2. Potential teaching and learning scenarios in VR
3. Characteristics of teaching and learning scenarios in VR
4. Technical requirements
5. Forms of support for teacher educators and student teachers

Findings

The interviews conducted with preservice teachers and teacher educators revealed a number of findings on the expectations of both groups regarding the design of learning and teaching processes in VR in educational contexts. In the following, selected findings will be summarized systematically based on the derived categories.

1. Experiences with VR

The preservice teachers in the sample had few learning opportunities with VR in their studies. However, they used VR in their leisure time on gaming consoles. Having gained teaching experiences with digital media in the local initial teacher education program, teacher educators brought along multiple prior experiences with VR that range from implementing VR systems in seminars to promote competences (e.g classroom management strategies) on a regular basis, to using VR applications only from now and then as tools for designing classes. Approximately half of the sample of the teacher educators described using VR in their seminars with preservice teachers. The other half, however, although having basic knowledge about VR, has few or no practical experiences implementing VR in seminars.

2. Potential teaching and learning scenarios in VR

Preservice teachers imagined VR to be useful in the classroom for the presentation of information, e.g., "how does an active volcano work?", that otherwise would not be possible, too costly or too dangerous to show to students. In the teacher educator interviews, participants developed various potential scenarios for using VR in initial teacher education. Phases of regular seminars were mentioned, e.g., group work phases or presentations. The teacher educators also suggested using VR to display locations and objects which would otherwise not be accessible. Also, role plays in VR were mentioned to allow for practice in challenging situations.

3. Characteristics of teaching and learning scenarios in VR

Avatar representations

The design of the avatars as virtual representations of the participants was an issue controversially discussed for both preservice teachers and for teacher educators. Opinions in both target groups ranged from a preference of realistic representations to a tendency for abstract representations.

Several preservice teachers felt uncomfortable with the thought of an avatar that resembles too much a human being in its appearance and preferred abstract versions. They reported that being able to tell the virtual world apart from the real world gives them a feeling of security. The ethical and moral aspects of avatar representation was emphasized throughout the interviews. Main concerns referred to the possible consequences of data protection and personal struggles with discrepancies between self-image and avatar representation.

On the one hand teacher educators are in favor of a realistic avatar representation, they argued, e.g., that realistic representations could increase the potential for identification. On the other hand, abstract representations were preferred by some participants because they expected easier access to the virtual learning environment and a lower risk for cyberbullying.

Room design

For designing the learning environment, preservice teachers put spaces for collaboration as a priority. Several of them preferred a classroom that offers a range of learning spaces where groups could gather and work together on projects. They put an emphasis on the social interaction with their fellow students. In their opinion, the learning surroundings should be held simple and clean in style and thus would not distract from the central purpose of the scenario.

The superordinate room design criterion for teacher educators was flexibility. The environment should be easily adaptable according to their own needs and preferences, ranging from purist designs to playful, friendly and motivating. Examples mentioned in this context included references to subject contents, such as Ancient Rome environments for History, or a virtual gym for Physical Education students. Also, in the context of furnishing, flexibility plays a vital role for them. Overall, the virtual learning arrangement needs to reflect the pedagogical approaches and methods applied by teacher educators, which means that it should offer options for easy re-arrangement and for spawning and de-spawning tables, chairs, media, and other furniture items.

Communication and interaction in the virtual room

From the preservice teachers' view, communication and interaction in the learning environment were important aspects that should work in VR. They suggested how the communication and interaction could be supported by measures like, for example, implementing a mechanism that signals to the participants, either visually or auditory, who is speaking, or giving the chance of using emojis to convey moods or feelings.

With regards to communication, teacher educators emphasized the necessity to control and regulate the auditive range for specific participants or groups. For example, it was suggested to have members of a group only hear each other without distractions from other groups. Also, teacher educators wanted to be able to limit or extend their range of addressees. More specifically, this means being able to select whether an input is to be heard by a single addressee, by a group or by the whole audience.

Teaching and learning methods

Basically, teacher educators and preservice teachers expressed the need to replicate practices known from face to face teaching settings also in the virtual environment. This applies to teaching and learning methods, such as open and constructivist learning formats, and changing social formats.

Preservice teachers stated the advantage of dividing learning content into several workload units and the importance of using learning methods that involve social interaction. They see the benefit of working closely together with preservice teachers that focus on other school forms than themselves in their studies. Teacher educators again emphasized the importance of flexibility and wanted to have their student teachers work collaboratively in flexible social forms in the virtual environment. This includes working on one's own, in groups or in a plenary with the possibility to change formats easily. However, group works were prioritized in a majority of cases.

Media

A central matter of concern for both groups, teacher educators as well as preservice teachers, referred to the question of writing in the virtual room. As participants do not have a keyboard at their disposal when moving in the virtual space, suggestions to compensate for this include, e.g., virtual keyboards, speech to text transcription, or handwriting recognition. Some teacher educators also thought about designing learning scenarios without writing and notes at all, while others considered this a serious constraint.

4. Technical requirements

Both for preservice teachers and teacher educators, technical feasibility was a frequently mentioned request. According to the interviews, hardware and software have to be intuitive and user-friendly. The hardware should be portable and ergonomic. Furthermore, the software should be stable and well designed and support immersion. It is also desirable to acknowledge aspects of inclusive design, e.g., to account for visual and auditory impairments.

5. Forms of support/ desirable knowledge and competency acquisition

Overall, both preservice teachers and teacher educators expressed a need for manifold support. Formats mentioned include tutorials, workshops, administrative support, and supportive feedback and helping functions within the virtual environment.

The preservice teachers wished to be accompanied closely in their exploration and use of the virtual environment, e.g., by supportive staff. Great importance was put on the face-to-face introduction and supervision by teacher educators.

For teacher educators, the following areas had been identified as potentially important for their own continuing education: 1) Technological skills, i.e., the skills necessary to operate and handle the respective devices and troubleshooting; 2) Application scenarios and best practice examples; 3) Methodology and teaching and learning approaches applicable in VR; 4) Attitudes and knowledge concerning VR in education; and 5) Legal, social and ethical aspects. Teacher educators discussed these proposed contents for continuing education rather controversially. There was common consent towards the importance of technological skills, application scenarios and best practice examples, and attitudes and knowledge concerning VR. However, opinions diverged concerning covering the topic of methodology and teaching and learning methods. While some teacher educators considered this a core constituent of their continuing education, others were confident to be able to integrate the virtual reality application also on their own without specific pedagogical training, as long as other aspects such as handling and technical skills are assured.

Discussion and Implications

The findings summarized above are subject to certain limitations. With regards to the samples of the study, it is important to note that both groups were convenience samples of the local department of educational sciences. Hence, against the background of the qualitative research approach and sampling method the interviewees are not representative of their respective groups and thus the results may not apply to other preservice teachers and teacher educators in the same way.

Against this background, a number of conclusions can be drawn from the interview results. Overall, it becomes evident that both the samples of preservice teachers and of teacher educators show considerable heterogeneity in certain cases with regards to their ideas and requirements. With regards to application scenarios, this heterogeneity led both samples to construct familiar learning settings on the one hand and to extend these to new contexts on the other hand. Also, the references to avatar representation illustrate how personal ideas and preferences shape the demands future users of a virtual reality environment bring along. There is no clear tendency in either of the groups to prefer abstract or realistic avatars. Notably, this finding corresponds to controversial findings from related research, where the effects of the avatar design vary as well depending on the outcome of interest (Latoschik et al., 2017). Additionally, in case of room design, personal preferences significantly shaped heterogeneous ideas of an ideal learning environment within the virtual room.

These observations substantiate the conclusion – which was also suggested by teacher educators in particular – that flexibility appears as a key criterion for the design and feasibility of a virtual learning environment to be used in initial teacher education. Teaching and learning scenarios are highly diverse and depend on a dense network of factors with regards to claims that the virtual environment has to fulfill.

Furthermore, it is noteworthy that both preservice teachers and teacher educators described teaching and learning scenarios in close connection to the conditions known from face to face teaching settings. This refers, e.g., to the design of the classroom, to learning formats, and to tools and media required, where the participants favored a realistic replication of face to face settings. Consequently, restraints from a technical perspective, e.g., with regards to the issue of writing or handwriting, were partly considered a serious limitation. Several teacher educators claimed to refuse a redesign of their methods and approaches to account for the new circumstances proposed by the virtual environment. Also, innovative ideas and approaches to teaching and learning were comparably scarce.

Hence, it appears a research desideratum for future studies to balance the innovative potential of learning scenarios in virtual reality and to respond to the demands expressed by potential users at the same time. Designing the environment in accordance with these demands is likely to increase acceptance and feasibility but at the same time limits the potential inherent in virtual reality for teaching and learning purposes.

In terms of technical requirements, both samples emphasized the importance of accessibility and user friendliness. Acknowledging this focus will account for the varying levels of skills both student teachers and teacher educators bring along with regards to the operation of digital media. Finally, considering the results on desirable forms of support, it became evident that both preservice teachers and teacher educators need to be supported and accompanied closely in their acquisition of respective competencies. As identified in the interviews, there are multiple ways to ensure that the competencies needed are acquired adequately, as, e.g., continuing professional development or administrative support. In the case of virtual reality in teacher education, such an extensive support appears especially important due to the different facets of competencies that need to be addressed with regards to educational and pedagogical competencies on the one hand and technical skills on the other.

Further research perspectives are conceivable. To substantiate the findings that build on subjective opinions, it will be necessary to triangulate methods and to contextualize the initial requirements of preservice teachers and teacher educators with experiences and data collected in the actual implementation of a virtual reality environment in initial teacher education programs. Against the background of the interview findings, it appears relevant not only to design immersive virtual learning environments but also to develop pedagogical concepts based on theory and empirical data to advance the competencies of preservice teachers and teacher educators appropriately. The data collected with regards to the demands preservice teachers and teacher educators have for teaching and learning in virtual reality offer significant insights into aspects to be considered in this context. In accordance with emerging literature from the perspective of educational research (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014; Southgate et al., 2019), it will be insightful to expand the perspective and to evaluate teaching and learning processes in virtual reality not just from a technical, but also from an educational and pedagogical perspective, based on the foci proposed above. This way, a pedagogical design-based research approach (e.g. Tulodziecki et al., 2013) can contribute to the further exploration of virtual reality in teaching and learning processes to make sure that future teachers can benefit from the potential VR offers.

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3.3 Conclusion

In this chapter, teacher educators' and pre-service teachers' requirements for a pedagogical concept to prepare both target groups for the successful implementation of VR in ITE were analyzed and evaluated. Insights gained from existing theoretical and empirical research, as well as from conducting qualitative interviews with teacher educators and pre-service students, allowed the first design hypotheses for the pedagogical concept to be derived (see Euler, 2014) using social VR in ITE. The results of the study showed that if neither educators nor students have gained sufficient experience of fully immersive VR in class, there should be close guidance and support when integrating VR hardware and software in seminars. The material and learning surroundings should be accessible and user-friendly. Moreover, teacher educators agreed that the pedagogical concept should consider elements of constructivist learning theory (Section 3.2); these empirical results are in accordance with the existing scientific literature (Huang & Liaw, 2018). Furthermore, both groups emphasized the need for disruption-free communication, collaboration, and interaction in social VR, imagining the possibility of varying social formats in group work (Section 3.2). Further, in line with cognitive load theory (Chandler & Sweller, 1991; Parong & Mayer, 2021), the teacher educators pointed out that design elements should be kept minor and clean so the social VR's surroundings do not distract students from learning (Section 3.2).

Since the objective of this research was to develop a pedagogical concept fostering pre-service teachers' TPACK in social VR, the first study explored important contextual factors, in particular those concerning communication and interaction processes, which allowed the first design elements of the pedagogical concept to be derived. However, the design principles were preliminary and required further research and development. Necessary adaptations and improvements followed the application of the design measures in practice.

4. Preservice Teachers' Encounter with Social VR – Exploring Virtual Teaching and Learning Processes in Initial Teacher Education

4.1 Aims of Study 2

Conclusions were drawn from the results of the needs analysis (Chapter 3) regarding the design of the pedagogical concept and the social VR environment. Following Euler's (2014) recommendation, an important next step was to develop a targeted and robust intervention before evaluating the design in a broader context. Accordingly, in the second study, a pedagogical concept was developed and implemented in a seminar session in a social VR learning environment with a convenience sample of pre-service teachers at a German university (Section 4.2). Doing so enabled an exploration of how the pedagogical concept could be implemented into a fully social VR learning environment in practice, as well as the consequences for the further development of the pedagogical concept and the social VR learning environment and their interplay. Furthermore, and in line with Bower and Sturman's (2015) reminder that "if the use is there but not perceived, then it is of no educational benefit" (p. 345), the pre-service teachers' perception of the teaching and learning activities in the social VR learning environment and its affordances are of central importance. Thus, the second study investigated the following research questions:

- How do pre-service teachers perceive teaching and learning activities in fully immersive VR?
- How should teaching and learning processes using social VR in teacher education be designed?

The results led to further insights into the development cycle of the pedagogical concept to foster the TPACK of pre-service teachers and its implementation in social VR.

4.2 Study 2

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Preservice Teachers' encounter with Social VR – Exploring Virtual Teaching and Learning Processes in Initial Teacher Education

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Abstract: With 21st century challenges ahead, higher education teaching and learning need new pedagogical concepts. Technologies like social VR enable student-centered, action-oriented, and situated learning. This paper presents findings of the pedagogical implementation of a distributed social VR prototype, a fully immersive VR learning environment, into an Initial Teacher Education program in Germany. The exploratory study addressed the following research questions: 1) How do preservice teachers perceive teaching and learning activities in fully immersive VR and 2) how should teaching and learning processes using social VR in Teacher Education be designed? It followed a design-based research approach. The pedagogical concept for teaching and learning in social VR was based on principles of action-orientation. A convenience sample of three groups of five students each took part in a 90-minute teaching and learning scenario using a fully immersive VR learning environment. During these seminar units, students engaged in qualitative group interviews and shared their perception of the action-oriented teaching and learning activities in VR. The results showed that preservice teachers had the feeling of being less distracted in social VR. Additionally, during group activities, missing social and behavioral cues made communication procedures more challenging for participants. However, some participants noticed a stronger sense of community while collaborating with others.

Introduction/ Study context

During the pandemic, the transition from classroom teaching to virtual instruction has emphasized the necessity to promote teachers' pedagogical media competencies from early stages on in Teacher Education (Ferdig et al., 2020).. Already existing demands for Information and Communication Technology infrastructures, innovative concepts embracing technology infusion, and action orientation in seminars are still pressing (Foulger et al., 2019). However, to meet expectations that envision teachers to be "fully capable of taking advantage of technology to transform learning" (US Department of Education, 2017) and for additional pedagogical value and improved learning outcomes, the sole implementation of technology in classes is not sufficient (Blömeke, 2017; Eickelmann et al., 2019, Foulger et al., 2017, Krumsvik, 2014). The effective use of emerging technologies for pedagogical purposes also includes promoting preservice teachers' media-pedagogical and ICT-related competencies (Blömeke, 2017; Eichelberger & Leong, 2019; Tondeur et al., 2019; Tulodziecki et al., 2017, Tiede & Grafe 2019). Consequently, learning scenarios in higher education need to offer opportunities for teacher candidates to gain in-practice experiences using and reflecting on digital media in initial teacher education (Borthwick & Hansen, 2017). Social VR is already being used actively in education and training programs and could promote constructivist learning environments that embrace situated and action-oriented learning in teacher education (Dawley & Dede, 2014; Hellriegel & Cubela, 2018). However, there is still a lack of studies dealing with the design and development of pedagogical concepts and best practices for social VR in teacher education.

Against this background, this exploratory research study focuses on the pedagogical integration of a fully immersive social virtual environment into a teacher education course in Germany. We aim to answer the following questions:

1) How do preservice teachers perceive teaching and learning activities in fully immersive VR?
2) How should teaching and learning processes using social VR in Teacher Education be designed?

We hope the results may be valuable for elaborating pedagogical concepts using social VR in initial teacher education.

Literature Review

Social VR

Years of enhancing immersive virtual reality technology lead to the use of VR on a mass-market scale (Perry, 2016b; Scavarelli et al., 2020). Developers and companies are still facing, however, ongoing challenges such as developing VR headsets with increased mobility, designing VR applications according to current standards, and considering ethical concerns (Slater & Sanchez-Vives, 2016). With user-friendly hardware and software becoming affordable, immersive VR attracts a wide range of consumers from different backgrounds approaching the technology with varying demands such as gaming, socializing, or collaborating in formal or informal contexts.

When emphasizing the use of VR's potentials to promote virtual and synchronous social collaboration and interaction in diverse contexts, the terms "social VR", "collaborative virtual environments", "immersive multi-user virtual environments or "collaborative VR" are sometimes used interchangeably. The virtual environments which are described by these terms share the characteristics of being " a web-based social interaction paradigm, mediated by immersive technologies and taking place in predesigned three-dimensional virtual worlds where individuals, represented by an avatar, may engage in real-time interpersonal conversation and shared activities" (Dzardanova et al., 2018).

Sharing the same definition, the term social VR, when used by commercial companies, underlines the immediate virtual environment's attachment to social media and its primary purpose of social networking. Dzardanova et al. (2018) describe the change towards social media's use in VR as "the second generation of social networking." Social VR applications like AltSpace, VRChat, or RecRoom attract increasing numbers of users that enjoy interacting with the VR experience (Gunkel, 2019). According to the authors the four key uses for social VR, in the understanding of a social networking platform, are "video conferencing, education, gaming, and watching movies." The question, which one of the key uses, does profit the most from social VR is open to discussion (*ibid.*).

Regarding VR's usefulness for education, there is disagreement about whether the additional effort and expenses required when implementing VR in class do justice to the added value on learning outcomes (Radianti et al., 2020). Regardless of their purpose, technically, social VR platforms seek to improve as best as possible the feeling of "being there together" in VR. Whereas 2D digital media and single-user VR systems lack in mediating the whole sensory impression of social encounters, immersive embodied multi-user virtual environments (MVEs) provide the possibility of communicating and interacting with each other via avatars, thus coming close to "real/offline" social communication and interaction. People can deal with and successfully interpret a wide variety of artificial and/or augmented signals to carry social meaning (Roth et al., 2018). However, implementing head and body tracking, a faithful avatar representation, spatialized audio, and natural nonverbal communication cues lead to reinforcing a "close-to-reality "experience (Latoschik et al., 2019). Thus, the sensory impression of diving into a simulated "real" world including artificial bodies intensifies prominent VR factors like the degree of immersion, presence, and virtual body ownership (Roth et al., 2017; Roth & Latoschik, 2020). If the sensory perception of the virtual environment is designed as closely as possible to reality, the brain does not differentiate between "real" or "virtual" sensory perception and, as a consequence, interpret them as real stimuli in VR (Slater & Sanchez-Vives, 2016; Slater & Steed, 2000).

Teaching and learning processes in social VR

Social VR's potential for teaching and learning processes lies within offering authentic learning environments that enable to interact remotely and synchronously as well as to permit learning experiences that affect learners in a multi-sensory way. Schwan and Buder (2006), stressing the advantages of the authenticity and interactivity of virtual environments, categorize virtual environments according to the user's level of interactivity with the virtual world into three types (Schwan & Buder, 2006): (1) In the focus of the *Exploration Worlds* is the sensory experience and self-paced exploration of objects, places or rooms that otherwise would be too difficult, not feasible or too dangerous to access. Learners can walk through virtual museums or travel to places they have never been before (*ibid.*), gathering information on their own or in groups. The National Geographic "Explore VR" App, for example, enables the user to walk through the historical site of Machu Picchu, and while fulfilling short tasks on the way, the user learns about Incas' history. The virtual environment provides information in multimodal ways and can thus promote declarative knowledge acquisition. Whereas interactivity is restricted in Exploration Worlds, (2) *Training Worlds* offer more potential to train procedural knowledge and psychomotor skills through action-based sequences in scenarios like evacuation drills (Feng et al., 2018). The advantage of using VR to train psychomotor skills is that situations can repeatedly be simulated under the same circumstances over and over again. Otherwise, in real life, this procedure would not be possible due to high costs, efforts, or the risk to harm people. (3) *Construction Worlds* have the highest possibility of interactivity for learners and virtual environments. In these worlds, users themselves can create and design objects inside the virtual environment.

Increasingly, software is released that enables VR's users to create their own 3D objects or express their ideas with drawing and modeling tools. The results are available in different formats and exportable to other media. Such a categorization might be helpful to distinguish between different virtual worlds. However, the chosen terminology refers only to exploration, training, and construction, therefore concealing its potential for important other learning activities, such as problem-solving, decision making, and critical thinking. Designing pedagogical concepts for teaching and learning processes in social VR on the grounds of constructivist learning theories offer great potential for promoting various competencies of learners (Burdea & Coiffet, 2003; Dawley & Dede, 2014; Scavarelli et al., 2020; Wang, 2020).

The integration and implementation of social VR for teaching and learning purposes are connected to some challenges. For one, the development of social VR platforms takes time and is extensive regarding resources. VR software and content suitable for teaching and learning settings are rare and need further development. Concepts and best practices that introduce teachers to how to use social VR in classes with materials explaining step-by-step procedures are missing (Stavroulia et al., 2019). Also, there are technical challenges concerning the choice of hard- and software. With the development of social VR platforms and thus making social VR commercially accessible for a bigger audience, also ethical questions arise in the context of users' data protection, harassments in open social VR places, fraud or avatars' influence on one's identity (Shiram & Schwarz, 2017). This makes designing teaching and learning processes in social VR quite challenging, as not only the pedagogical view has to be considered but also the technical characteristics of social VR have to be taken into account.

By exploring teaching and learning processes in social VR and how they are perceived by preservice teachers, the present study seeks to give valuable insights for further developments of pedagogical concepts for teaching and learning in social VR. Based on the needs analysis of Ripka et al. (2020) the following conclusions have served for the development of the pedagogical concept and the social VR prototype used this study:

1) Design of action-oriented and constructivist teaching and learning scenarios with changing social formats
2) Preservice teachers are supported in their exploration and the use of the virtual environment.
3) Room design of social VR must be clean and simple, allowing interactivity and social collaboration
4) Communication and interaction in social VR should work easily without interruptions
5) Avatar representations can either be abstract or real

Research Methodology

1. *Study Context*

The overall goals of the research project are the design of a theory and practice-based pedagogical concept for promoting media-pedagogical competencies using social VR in Initial Teacher Education (ITE) and the interdisciplinary development of an according social VR platform. As a result of this iterative design process, the social VR platform will be integrated into seminars in ITE at university and used as a distance teaching and learning tool that promotes media-pedagogical competencies of preservice teachers. In this developing process, following up on the needs analysis of teacher educators and preservice teachers' requirements for teaching and learning in social VR (Ripka et al., 2020), this study focuses on the following research questions:

1) How do preservice teachers perceive teaching and learning activities in fully immersive VR?

2) How should teaching and learning processes using social VR in Teacher Education be designed?

2. *Study design*

Social VR prototype

Regarding room design, the social VR prototype, based on the game engine Unreal Engine 4.24 and optimized for Microsoft Windows 10, offered a fully immersive seminar room. The *Oculus Rift S*, a Head Mounted Display, and a Laptop served as VR hardware. To avoid unnecessary distractions for the students, the virtual seminar room is kept clean and simple, offering room for collaboration and interaction.
The implemented virtual whiteboard enables the teacher to use webpages, presentation slides, and collaborative web tools throughout the seminar session. The board can be

operated with a control board integrated into one's avatar's virtual wristband. For avatar representation, a comic-alike abstract avatar is used. Outer appearances like the color of the upper body, gender, and name are customizable for the users. After entering the preferred avatar choice, representations' names appear over the avatar's head, visible for all participants. Students are able to move around via teleporting.

Pedagogical Concept

For the preparation of students using the VR hard-and software, a face-to-face introduction had been performed before the seminar started. In addition to a hands-on approach throughout the process, with the aim in mind that students need to get used to the VR user interface, a collaborative and interactive group activity in the virtual environment was designed. A planetary system was simulated inside the virtual seminar room, and participants would have to communicate with each other to put the planets into the right spot. To be able to closely observe teaching and learning processes and to support students with getting used to VR's hard-and software, two main choices were made. First, the group of participants for one seminar session was restricted to five. Second, the intervention took place in one big lab instead of locally distributed to support students in case of having difficulties with the technology and to ease the detection of technical malfunctions and troubleshooting.

The pedagogical concept for the 90-minute seminar session was designed based on action- and development-oriented didactics (Tulodziecki et al., 2017; Tulodziecki et al., 2019) combined with flipped classroom principles. This involved a task-based approach and collaborative learning processes in the virtual learning environment. Students prepared the learning content for the seminar session in advance according to flipped classroom principles. The seminar session was divided into two units:
(1) a teacher-centered introduction of the topic and the presentation of a situated task asking the students to design a concept for using VR in schools which was followed by a joint brainstorming (10 minutes),
(2) a learner-centered group activity in which preservice teachers designed a concept for using VR in the classroom with pupils and presented their results at the end of the session (30 minutes).

3. *Methodology and data collection*

The convenience sample consisted of 15 preservice teachers (3 groups of 5 students each). Due to sickness one of the students did not appear. The students had the opportunity to sign up voluntarily for the intervention which was promoted in school pedagogy courses focusing on the use of digital media in educational contexts. The participants represented a mixed group of 12 female and 3 male teacher candidates. Group 1 and group 2 consisted each of five female students. Three male and two female preservice teachers participated in group 3. Data was collected qualitatively in group interviews.

The development of the interview guide was based on the central components of teaching and learning with technology, according to Tulodziecki et al. (2019), and the requirements of teacher educators and preservice teachers (Ripka et al., 2020).

I. Teacher-centered teaching and learning processes
    a. What is your experience with the social VR application?
        a.i. When you think of your seminars in "real" classrooms, how did you perceive the interaction with the lecturer in comparison?
        a.ii. What advantages and disadvantages do you see in learning in social VR?

II. Learner-centered teaching and learning processes

a. You have worked together in the group activity in VR. The sketch of the design task is the result of this group work. What was your experience during the group work in VR?
    a.i. What experiences have you had during the process of finding mutual consent in VR?
    a.ii. What was your experience in giving mutual feedback?
    a.iii. What was your experience with consultations within the group?
    a.iv. Which other functions in VR would have been helpful in the group activity?

The group interviews took place in-between seminar units and outside of VR. The interviews were recorded, transcribed, and analyzed through qualitative content analysis (Mayring, 2015). They were coded using MAXQDA (Rädiker & Kuckartz, 2019). The following categories were determined deductively following the approach of Mayring (2015):

1) Teacher-centered teaching and learning processes
    a. Interaction between lecturers and students/ students and students
    b. Interaction with social VR environment
    c. Communication and language in social VR
    d. Media pedagogical content
2) Learner-centered teaching and learning processes
    a. Interaction between lecturers and students/ students and students
    b. Interaction with social VR environment
    c. Communication and language in social VR
    d. Media pedagogical content

Also, an exploratory participatory observation was carried out to help interpret the results of the group interviews.

Results

1) *Teacher-centered teaching and learning processes*
    a. Interaction between lecturers and students/students and students

When asked about how they perceived the interaction with the lecturer in social VR in comparison to "real" classrooms, one student said that it would not differ so much, "Well, I think it was not much different [...] I think you need a few minutes to get used to it. But you see and hear quite good who is talking and what it is all about" (Group 1_C). Some participants experienced a shift of focus in VR, and one explained, "I had the feeling that somehow the attention of us lay much more crassly on what was said, [...] I think the focus was just completely different because I cannot be distracted" (Group 2_C). Further, describing the perceived relationship between the students and the lecturer in social VR students commented for example: “I don't know if this is due to the format, but I thought that it wasn't a real teacher-student relationship because we were standing in a circle and also much closer together. The classroom is usually bigger, and you have more distance to the teacher and he usually stands in the front. I thought that was the group feeling that was addressed, not only including the students but also the teacher” (Group 3_D).

b. Interaction with social VR environment

Regarding their experiences with the social VR environment, some students reported unease while getting used to the VR environment: "I thought it took a lot of time to get used to it. In the beginning, I didn't know at all if this is a blackboard" (Group 1_E). Concerning the change from the "real classroom" to the VR environment one student stated: "So it was just a strange feeling to be in another room from one second to the next" (Group 2_A). Others valued that there were no distractions in the virtual seminar room: "There is no window, where I can distract myself from any people who might be walking around, [...] I don't have anything that tempts me" (Group 3_C). Emphasizing the positive effects of a mobile-phone-free learning surrounding a student said: "If I sit in a face-to-face seminar for example, then 80% of the students have their mobile phones at the table [...] but this doesn't work here, and because of that, I don't have the possibility at all, I think the focus was completely different because I can't be distracted" (Group 1_C). Referring to the effects of wearing VR headsets over a specific time-period, most participants agreed on the following impression: "At the beginning, I thought: Super interesting. And at some point, you realize: It's getting super tiring to look at the virtual board and to concentrate" (Group 2_C).

c. Communication and language in social VR

As abstract avatars represented participants, facial expressions, and full body gestures were missing. The consequences influenced the way of communicating and interacting in social VR. Several participants observed positive effects of missing communication cues, as these examples show: "I also agree with what you said about concentrating on the language because somehow, I don't have to concentrate on facial expressions and gestures and my appearance, and everybody is looking at me" *(*Group 3_B) and some felt more comfortable to talk, pointing out: "But I think you also have a little less inhibition to say something because you feel so anonymous [...]" (Group 2_B).

d. Media pedagogical content

There were no comments regarding the media pedagogical content.

2) Learner-centered teaching and learning processes

a. Interaction between lecturers and students/ students and students

Regarding the interaction between students in the second collaborative unit of the session, most of the participants thought that the group work in social VR was not too challenging, as this statement shows: "Well, I thought it went very well, I didn't think that we would come to a result so quickly. I know it from other group work, where you discuss forever and then I heard a quarter of an hour, I was like "Oh god oh god", four of us, four opinions in a quarter of an hour, but it went well, so we agreed relatively quickly, and were all happy with it" *(*Group 3_C). Referring to the learners' proximity of the learning setting in VR compared to a real classroom one, a student thought, "it's better because somehow you have the feeling that you can't retreat. Because we all see each other. We are all standing in this circle and it would also be noticeable if one of us just wouldn't do anything" (Group 1_C). Also, during this process, the missing social cues influenced the communication between students. As one participant expressed: "I can also imagine that when you do this in larger groups, I mean we are a really small group now, it can sometimes be a bit confusing when you have to assign the voices, because you don't see that someone is speaking, and then you are a bit confused" (Group 3_D).

b. Interaction with social VR environment

Several participants described positive consequences using the social VR environment, stating for example, "Well, I would say that I think: I'll just profit more of it. Because somehow - I don't know - I feel more like I'm present" (Group 1_C). Additionally, one participant pointed out social VR's potential being a "safe place" in that one could act without fearing consequences: "I think it is really good if you don't have any direct consequences, so you can really test a lot. And if it goes wrong, then you just do it again or something like that. Things that you could not do at all, or if you have to do them once, you do them once. I think that's a very, very big opportunity" (Group 1_A). However, other students expressed their concerns: "I think it's a difference if you put on your glasses and you have everything already in place than having to create it yourself, especially if you are technically a bit insecure [...] I think I would - personally I'm afraid of it - so I'd be really afraid, if I really could manage that - especially with students" (Group 2_A). Also, some wished to be able to take some notes: "...what I missed, was that you can't take notes. Because it takes a bit longer and everyone gives input, and so on - you can't take notes" (Group 2_D).

c. Communication and language in social VR

Similar to the teacher-centered phase, the missing social cues lead to more challenging communication: "So, what you really have to get used to: You really have to approach people directly. By name, really. You really have to get into the habit of addressing people directly by name. Because otherwise you really don't feel addressed" (Group 2_D).

d. Media pedagogical content

Regarding the lessons' content and its extent, several participants commented like this: "It would have been hard to memorize all this or not to write it down on the side. Especially when it is something bigger and longer that you can take notes on the side" (Group 2_A). Another student added:" I got more out of it than if I would have just sat there and written it down" (Group 2_C). Concerning the potential of using VR in their future classroom, students described examples of how they can imagine getting their pupils involved in learning content: "[...] for example, when I imagine that I somehow deal with the topic of factory farming in class, and then just say that the chickens are totally cramped in cages, but I only have a picture, which perhaps doesn't concern anyone that much. But if I can really stand there in this farm with the help of social VR and look around and see how cramped these cages are, then it might be more enduring and impressive for me, and it keeps me more engaged, and then it might have more impact on my future actions and consumer behavior" (Group 3_B). Additionally, one student commented on the use of social VR from a more differentiated perspective: "I can perhaps imagine it quite well in the didactics, less in other disciplines, [...]but I think it's a good opportunity to try it out if you're designing a lesson with a group [...]" (Group 3_C).

Discussion and Implications

Concerning the further development of the social VR platform and the pedagogical concept for teacher education, the results and the participatory observation of the study are leading to the following conclusions and implications for the research questions:

RQ 1) How do preservice teachers perceive teaching and learning activities in fully immersive VR?

Results show that several participants pointed out that based on the virtual surroundings they focused more on the content shared. However, most of them agreed on the efforts that had to be made to read the presentation on the virtual whiteboard. As an improvement, few students would like to have the possibility of taking notes. Throughout the design task in the group activity, communication cues like facial expressions and gestures were missing leading to more time spent with managing communication flow. Observation showed that the speaker turns posed difficulty for two groups to anticipate. However, both groups started to compensate for the missing social cues. One group started to use hand signs. The other group concentrated on the avatar's upper body as a signal when the speaker's turn took place. Students commented on this and agreed that they felt losing valuable time to work together productively. Some recognized, however, that they had the urge to be more attentive and actively participating in keeping the workflow going. Shy students even felt they could participate in social VR more freely because, in their avatar representation appearance, they felt more anonymous and safer to speak.
Close to the end of the session, the majority agreed that wearing the VR headset would be exhausting, in particular when focusing on the digital whiteboard panel.

The exploratory observation of participants throughout the teaching and learning activities shows that preservice teachers were curious and open to the VR experience. Most of the preservice teachers got used to VR's hard-and software and did not need any technical support. Furthermore, the observation showed that the group task and the results' presentation were carried out from all groups without problems. However, taken from the results, some remarked that group size might be a limiting factor regarding fulfillment as communication was challenging.

RQ 2) How should teaching and learning processes using social VR in Teacher Education be designed?

Concerning the pedagogical concept, the observation showed that combining the seminar concept with the flipped classroom approach has proven beneficial for the action-oriented and situational teaching and learning processes in VR. As integrating social VR in teaching and learning processes takes more time, it was possible to use the seminar units in VR intensively to work on the subject matter without mentally overloading the participants. As results show, the lesson's extent of content was described as manageable; otherwise few participants stated they would have had to take notes. Overall, observations showed that all groups could perform the tasks. Technical limitations, such as the resolution of virtual media presentation, headset quality, and mobility as well as missing communication cues, made the seminar session in VR more challenging, however, did they not prevent the teaching and learning processes overall. Combining seminar sessions concerning 1) location (online/face-to-face) and 2) teacher-or learner-centered, on a selective basis, teacher educators and preservice teachers could profit from the positive effects on motivation to use VR in class themselves, group dynamics, and participation in VR, without being dependent on technical limitations. Results showed that most preservice teachers thought the VR experience to be exciting. However, this is possibly due to novelty effects. Also, some stated that they felt a sense of community and group feeling including the lecturer. Concerning the social VR environment, distraction-free surroundings seemed to help that students' kept focus. Keeping the balance between functionality and usability, the room design itself needs no change. However, it might be interesting to observe in future studies what effect different sceneries would have on preservice teachers. As missing social cues lead to challenges in communication and interaction during a group activity, supporting social cues should be implemented into social VR's functionalities.

On the one hand, restricted communication cues in social VR lead to positive effects. Interview results showed that several participants focused more on the spoken word and thus felt more involved in activities. Also, observation and results show that some of them tend to pay more attention to addressing their peers, and attentively followed the communication.

On the other hand, social cues are vital for communicating with each other and interpreting non-spoken context. Without the extra information included in communication clues, it takes more time to keep up the communication flow during group activities and might influence the learning process. According to Roth et al. (2016; 2018) the absence of social or behavioral cues can have impacts on social interaction in VR, such as decreased communication efficiency or decreased affective understanding. Leading to the assumption that learning processes might profit from the implementation of social and behavioral cues, further studies in this regard are needed.

The results summarized above are subject to certain limitations. Regarding the samples of this exploratory study, it is essential to note that a convenience sample was used. Hence, against the background of the qualitative research approach and sampling method, the interviewees are not representative of their respective groups. Thus, the results may not apply to other preservice teachers in the same way.

To substantiate the findings, more investigation is needed to observe how teaching and learning processes in social VR can be designed effectively. At this moment, the close interdisciplinary work between pedagogical and technical disciplines plays a vital role, as necessary pedagogical processes need to be enabled by the technical environment of social VR. It will be insightful to extend the observation to more seminar sessions with changing learning environments as well as changing teaching and learning scenarios. Moreover, a further step will be that interventions take place locally distributed. Regarding the shift to distance teaching and learning formats in higher education during COVID 19 pandemic, in connection to the most commonly used video-mediated platforms, social VR represents a possible extension tool to integrate action-oriented and situated learning in new pedagogical concepts for distance learning.

The findings from this exploratory study are currently incorporated into the further development of pedagogical concepts using social VR in teacher education. The provision of the pedagogical approaches and the developed materials as well as the social virtual environment as open source will contribute to the dissemination of social VR scenarios in different educational contexts. Thus, the presented social VR teaching and learning activities offer a wide range of transfer and possible uses for students and lecturers of different disciplines in higher education in the future, also promoting international mobility and inclusion.

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4.3 Conclusion

The aim of the second study was to analyze how pre-service teachers perceive teaching and learning activities in fully immersive social VR and to derive consequences for further refinement of the pedagogical concept to promote the TPACK of pre-service teachers. As indicated at the beginning of Section 4.1, the in-practice implementation of social VR for teaching and learning processes in ITE requires the close adaptation and interplay of pedagogical and technical components. Regarding pedagogical design elements, the results of the second study showed that flipped classroom principles prove beneficial for action-oriented activities and enable effective use of limited seminar time (see Section 4.2). Thus, it was possible to integrate more breaks in the seminar units, which may have relieved the strenuous cognitive processing (Chandler & Sweller, 1991) that can occur with social VR stimuli (Parong & Mayer, 2021). Further, study participants described a sense of community; such an experience can result from feeling co-present in social VR (see Dalgarno & Lee, 2010; Hacker et al., 2020; Slater & Wilbur, 1997). The results showed that they enjoyed the social interactions and performance of the group task (see Section 4.2).

Regarding the social VR learning environment, the results of the second study indicated that social interactions without disruptions are highly important. Although the successful performance of the group task was closely linked to the characteristics of social VR, such technical restrictions as missing social cues, avatar representations, or content representation made social interactions more difficult. However, the missing cues also had beneficial effects, such as increased focus on spoken words by learners. Further, the results suggested that many breaks, close supervision, and monitoring in social VR can build a supportive frame for learners. In line with this, investing time in providing IT support can prevent major disruptions during seminars, particularly when done at the start of the session (Section 4.2).

In summary, considering the pedagogical and technical implications derived from the literature as a theoretical frame of reference (Euler, 2014), as well as the empirical results of the second study regarding students' perceptions, the following design principles of the pedagogical concept using social VR were implemented in the next design circle (Euler, 2014):

- Active learner engagement with the subject matter.
- Group tasks for small groups.
- Flipped classroom principles and action orientation.

- Clear and structured content representation to prevent students' cognitive overload.
- Use of the potential of the feeling of being together in social VR.
- Close support from a pedagogical and technical perspective.

5. Peer Group Supervision in Zoom and Social VR – Preparing Pre-service Teachers for Planning and Designing Digital media -integrated Classes

5.1 Aims of Study 3

In the first two studies carried out for the current research, contextual factors for a pedagogical concept to foster the TPACK of pre-service teachers in social VR were analyzed and explored by implementing a prototypical pedagogical concept to promote such TPACK using social VR on campus (Sections 3.2 and 4.2). In the third study, the pedagogical concept was refined by integrating further design principles and shifting from the lab setting to distributed teaching and learning processes in social VR (see Section 5.2).

Following the key objective of this work—namely, to promote pre-service teachers' TPACK as metaconceptual awareness (see Section 2.1)—the pedagogical concept aimed to foster metaconceptual learning processes, such as scaffolding, reflecting, and modeling instructional designs (see Section 5.2). In this vein, at the core of the investigation is the integration of the peer group supervision approach, as Tietze (2010) described.

Starting a new iterative cycle of refining, testing, and evaluating the implemented design principles (see Euler, 2014), Study 3 aimed to create a robust intervention before the final evaluation of the pedagogical concept for the promotion of pre-service teachers' TPACK in social VR (see Section 6.2). Further improvements in the design of the pedagogical concept were investigated in further pilot testing (see Euler, 2014). Furthermore, the implementation of the pedagogical concept in social VR was compared with the use of a video-based conference system, a tool commonly used in higher education (Pelletier et al., 2021). Thus, the study addresses the following research questions:

- How should a pedagogical concept for remote ITE be designed to promote the metacognitive learning processes of pre-service teachers?
- How do pre-service teachers perceive these learning processes in video-based communication and social VR?

The results of the study were used in the final evaluation of the pedagogical concept of fostering the TPACK of pre-service teachers in social VR.

5.2 Study 3

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Peer group supervision in Zoom and social VR- Preparing preservice teachers for planning and designing digital media integrated classes

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Abstract: 21-century challenges demand a change towards collaborative and constructive seminar designs in initial teacher education regarding preservice teachers acquiring meta-conceptual awareness (TPACK) about how to implement emerging technologies in their future profession. Against this background the paper addresses the following research questions: 1) How should a pedagogical concept for remote initial teacher education be designed to promote metacognitive learning processes of preservice teachers? 2) How do preservice teachers perceive these learning processes in video-based communication and social VR? Regarding the pedagogical concept, peer group supervision and an action- and development-oriented approach using Zoom and social VR were identified as relevant for an instructional design that provides collaborative and constructive learning processes for students. In this exploratory study, 17 students participated in two iterative cycles of peer group supervision performing design tasks in groups. A content analysis of reflective video statements and qualitative group interviews was carried out using a qualitative research design. Results indicate the successful implementation of peer group supervision. Regarding media's implementation, Zoom's screen-sharing option and breakout session benefitted the consultation process as well as social VR's "realistic" experience of creating a "sense of community".

1. Introduction

The pandemic emphasized the need for new concepts in initial teacher education to prepare preservice teachers for 21st-century challenges. Shifting from f2f to remote teaching in education, teachers at all school types had to promote students' competencies with a set of available digital tools. Social distancing has restricted communication and collaboration to a specific limit with the consequence that teachers must put more effort in adapting, especially collaborative constructive learning activities to foster students' engagement in online learning scenarios. As most instructional designs in teacher education rarely offer constructive learning scenarios allowing technology integration (Foulger Teresa S. et al., 2017), there was a rise in teachers networking on social media platforms to support each other as a community of interest with methodological know-how for effective media integration into remote teaching and learning scenarios (Hacker et al., 2020). Most teachers did not feel prepared well enough for the complex task of planning, designing, and reflecting learning scenarios with emerging technologies, as this implies a sound knowledge of technology, pedagogy, content, and, more importantly, about how to transfer this knowledge into action. This in turn involves higher-order thinking skills such as reflective and problem-solving thinking processes that offer the potential to promote collaborative, constructive, and meaningful teaching and learning.

Hence, there is the need to design seminar concepts that provide student teachers with diverse learning opportunities, as early as possible in initial teacher education (ITE), offering incentives for the development of metacognitive learning processes as well as promoting, urgingly, media pedagogical competencies that prepare them for their complex tasks in their future profession (Blömeke, 2017; Foulger Teresa S. et al., 2017; Ripka, Tiede et al. 2020).

Against this background, this work will investigate the following two research questions:

1) How should a pedagogical concept for remote initial teacher education be designed to promote the metacognitive learning processes of preservice teachers?
2) How do preservice teachers perceive these learning processes in video-based communication and social VR?

2. Literature Review

TPACK as meta-conceptual knowledge

Between 2009 and 2020, more than 844 works have been published that contribute to the research on TPACK (Tseng et al., 2020). As an extension to Shulman's pedagogical content knowledge concept (Shulman, 1987), Mishra and Koehler (2006) introduced the conceptual framework TPACK. It addresses not only the mere technical aspects of using technology in educational contexts but also the multifaceted and complex pedagogical and content-related implications that go along with it. According to the authors, the framework comprises three core knowledge bases (technological, pedagogical, and content knowledge (TK, PK, CK)) and its intersectional components (technological pedagogical knowledge (TPK), technological content knowledge (TCK), pedagogical content knowledge (PCK), technological pedagogical content knowledge (TPACK)) that describe teachers' knowledge of using emerging technologies effectively in educational contexts *(ibid.).* To explain how the knowledge domains interplay with each other and how TPACK is constituted there are two main perspectives in literature: the integrative and transformative view. In the integrative view, "high levels of TPCK will be constituted by high levels of TPK, TCK, PCK, TK, PK, and CK" whereas in the transformative view "TPCK cannot simply be accounted for by summing all other TPACK components, but rather it is a distinct form of knowledge which transforms beyond the components at its base" (Schmid et al., 2020) This work, however, deals with TPACK as a meta-conceptual knowledge as outlined in the following.

Regarding learners' development of TPACK, Mishra and Koehler (2006) point out that "learning through design embodies a process that is present in the construction of artifacts". In this "learning-by-doing" process, learners are supposed to engage actively "in practices of inquiry, research, and design in collaborative groups" (*ibid.*). Taking the design of lesson plans into focus, Zohar and Schwartzer (2005) indicate that design tasks are complex tasks that "require higher-order thinking in TPCK". Preservice teachers are supposed to make multiple decisions when integrating technology in class, considering contextual factors involving critical thinking and problem-solving. They need to (a) plan and design appropriate learning activities for teaching and learning scenarios with technology (b) choose digital media and content to use in teaching/learning and why; (c) embedding it in the pedagogical method to support that choice (d), deciding when and how to use it (Kramarski & Michalsky, 2010). As an elaboration of the transformative view on TPACK, based on the assumption that the TPACK framework also comprises the metacognitive learning processes involving higher-order thinking, Krauskopf et al. (2012) see TPACK as a meta-conceptual awareness that considers metacognitive aspects integrated into TPACK. This coherent theory is based on the notions that constructing mental models, that comprise a variety of aspects needed to design a lesson plan serve as "mediating variables between a teacher's abstract knowledge and planning the integration of the respective tool into their teaching", and thus lead to TPACK as a "higher mental model" (Krauskopf et al., 2012).

Against this background of TPACK being considered as a meta-conceptual awareness (Krauskopf et al., 2012; Krauskopf et al., 2018) this work follows two lines of thought that set the baseline for the design of a pedagogical concept in remote initial teacher education. First, teachers need to construct complex mental models of integrating technology effectively in class for the development of media-pedagogical competencies *(ibid).* Second, to develop these complex mental models, higher-order learning and collaborative, constructive learning processes are required, leading to TPACK as meta-conceptual awareness of how to implement emerging technologies in class.

Therefore, in the following, peer group supervision as a potential concept to promote collaborative, constructive learning processes will be outlined.

Peer group supervision

In teacher education, peer group supervision refers mainly to peer coaching approaches for in-service teacher's professional development. Since the early 1980s, more and more peer learning approaches have been implemented in preservice teacher education. Only a few studies however consider peer group supervision as a pedagogical approach in initial teacher education (Tietze, 2021). In this paper, the term peer group supervision follows the German concept of *kollegialer Fallberatung* of Tietze (2010) and related concepts (Richard & Rodway, 1992). It describes the process of people with the same profession share, reflect, and discuss problems or questions related to their profession. Although one could assume based on the word "supervision" that there is a hierarchical order, the participants are neither subordinate nor superior to each other regarding power structures. The peer group supervision's main goal is that the participants conclude future actions for their profession through peer feedback and self-reflection (Tietze, 2010).

To distinguish peer group supervision from other similar concepts, Tietze names four critical features of peer group supervision:

(1) the concept must take place in a *group*. The author suggests building groups of five to ten participants depending on the existing conditions.

(2) *questions and cases* addressed are related to a shared profession. Cases should refer to an experienced professional role conflict, dilemma, or problematic interaction. Beyond this, they should also be of personal significance. The participant contributing to the case should be personally involved in it and have a personal interest in new perspectives (Tietze, 2010; 2021).

(3) according to Richard and Rodway (1992) most *consultation processes* follow a basic form of a four-phase structure: (a) The peer group supervision process starts with a participant's request for help, (b) the person presenting the case is exposing more information about it, (c) the group reacts to the question and the case focused on, giving room for further inquiries on the case and deepening the understanding of the presented information, (d) a decision or reflection on further possible actions is taken. The phases help participants as guidelines for communication processes, and thus also support "systematic problem-solving, such as a clear separation of problem description and solution development" (Tietze, 2021). Throughout the peer group supervision process, multiple perspectives play a particularly important role. By working on problems, questions, and cases from different angles, they can be viewed and reflected upon more closely and perceived in their complexity (Hesse & Lütgert, 2020).

(4) all *participants' roles* must be reversible. During the phases, participants fulfill reversible roles. Either participant takes the role of an advice seeker, presenting his/her question/case/problem to others, or he/she can support other advice-seekers as an advisor. Also, he/she can moderate the case consultation process in the peer group.

According to current research peer learning approaches based on constructive learning theories offer the potential to promote competencies needed for the teaching profession (Krauskopf et al., 2012; Krauskopf et al., 2018). Potential benefits of peer learning linked to observational learning based on socio-cognitive learning theory (Bandura, 1979; Tietze, 2010, 2021) are the development of confidence, self-esteem, collaborative skills, critical inquiry, and reflection. The authors also add to the benefits the communication and articulation of knowledge, understanding and skills, managing learning, and how to assess oneself and others (Boud et al., 2001)

Against this background, it is assumed, that with the integration of peer group supervision in remote initial teacher education, higher-order and constructive thinking processes are promoted and are leading to the development of TPACK as meta-conceptual awareness.

Web-conferencing systems and Social VR's affordances for peer group supervision

Digital media communication tools are used to replace or complement face-to-face communication. As during COVID-19, a high number of people were forced to use web-conferencing tools such as Zoom and Microsoft Teams, Hacker et al. (2020) investigated the affordances and constraints of web-conference systems for its users. To only name some of the affordances, the study's results lead to the conclusion that the use of web-conference systems supported the social co-presence of people and thus created "a social technology that led to a new virtual togetherness." (*ibid.)* Garrison et al. (2013) identified in their COI framework social presence as one core element of a collaborative constructivist learning environment required to create and sustain a purposeful learning community in online learning environments. Other works, however, show that computer-supported learning environments have limitations regarding synchronousness, non-verbal cues, physical proximity, spatial cohesiveness (Abfalter et al., 2012), and processing (Ferran & Watts, 2008) that might influence the feeling of "virtual togetherness" and thus limit the positive effects they assumingly have on collaborative constructive learning processes.

A medium that also favors mediated social interactions is social VR. Fully immersive VR as a communication and collaboration medium is widely applied and studied in a wide range of areas (Billingsley et al., 2019; Slater & Sanchez-Vives, 2016) Based on its main aspects such as immersion, presence, place illusion, plausibility illusion, and coherence (Bailenson et al., 2008; Latoschik & Wienrich, 2021; Skarbez et al., 2020; Slater & Steed, 2000), social VR offers the possibility of experiencing communication, collaboration, and interactions in VR close to the "real world" sensations. As in previous works outlined (Latoschik et al., 2019; Ripka, Grafe, &

Latoschik, 2020; Ripka, Tiede et al., 2020) fully immersive social VR's characteristics enable the planning and design of collaborative and constructive virtual teaching and learning processes. Yet, as with any medium, the sheer integration of VR in teaching and learning does not guarantee an additional value or improved learning success. A growing number of research works confirm its affordances and suggest additional values when it is included in educational settings reasonably. This however requires from designers of immersive teaching and learning scenarios the proper identification of social VR's appropriate implementation in line with learning objectives in lessons designs without overwhelming its learners (Johnson-Glenberg, 2018).

As communication and collaboration are two vital aspects of performing peer group supervision successfully regarding social learning processes, this work investigates how students perceive Zoom's and social VR's usage performing the peer group supervision cycles and its implications for learning processes.

3. Research Methodology

Against this background, built upon results of previous studies (Ripka, Grafe, & Latoschik, 2020) this paper investigates the benefits and challenges of peer group supervision in social VR in ITE to promote media-pedagogical competencies, focusing on the following research questions:

1) How should a pedagogical concept for remote initial teacher education be designed to promote the metacognitive learning processes of preservice teachers?
2) How do preservice teachers perceive these learning processes in video-based communication and social VR?

Study Design

Pedagogical Concept

The pedagogical concept was designed based on action- and development-oriented didactics (Tulodziecki et al., 2017; Tulodziecki et al., 2019) using complex tasks and a structured learning process combined with flipped classroom principles. Its primary pedagogical objective was the students' constructive and iterative design development of a technology-integrated instructional design in teaching and learning scenarios. According to flipped classroom principles, students prepared the learning content in advance asynchronously to perform design tasks throughout the seminar sessions synchronously. Course units comprised a combination of synchronous and asynchronous teaching and learning scenarios supported by digital media platforms such as LMS, Zoom, Miro, Flipgrid, and social VR. The course concept followed a sequenced four-stage structure with its primary focus on stages two and three, in that the peer group supervision cycles took place.

Stage I set the ground for the implementation of peer group supervision. Course sessions one to three covered a basic introduction to the seminar and media education, media competencies, and media design. In preparation for the first peer group supervision in session four, preservice teachers had to perform asynchronously a design task. Central to this task was the development and critical reflection of a technology-integrated instructional design in teaching and learning scenarios

Stage II starts with the first cycle of peer group supervision. The process was structured according to Tietze's peer group supervision's features (2010):

(1) The *group size* was limited to 3-4 participants. As one seminar session lasted 90 minutes, each participant should have the chance to present a case or a question.
(2) Students had to prepare a complex design task.
(3) The *consultation process* comprised three main phases á 10 minutes:
    a. The advice seeker presents his/her case. The others listen and do not interfere.
    b. The advice-givers ask questions to clarify the stated case and information
    c. The advisers offer ideas, information, or concepts that might help the advice seeker. A discussion or joint reflection can take place.
(4) Three *roles* were assigned: the advice seeker, the advice-giver, and the moderator who also visualized the consultation process results on the online collaboration board. The teacher educator is not present but has the task of being a facilitator that monitors processes and intervenes when necessary.

Following the first peer group supervision, to promote further reflective processes, students uploaded a reflective video statement on Flipgrid, a web-based application that offers a platform for classes to upload engaging media content such as personal video clips that motivate students to interact with each other. Students or teachers can feedback on uploaded content. In addition to individual feedback given by the teacher educator, all participants reflected together on the process of their peer consultation.

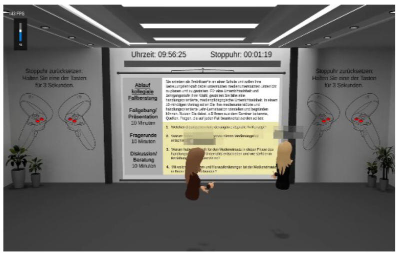
For the second peer group supervision cycle, based on the previous session's content on designing and planning technology integration into the classroom, preservice teachers got a second task to design an instructional design of their choice. To investigate how video-based communication and social VR's affordances favor or hinder peer group supervision, students were allowed to choose either form (Zoom or social VR) of communication and collaboration tool.

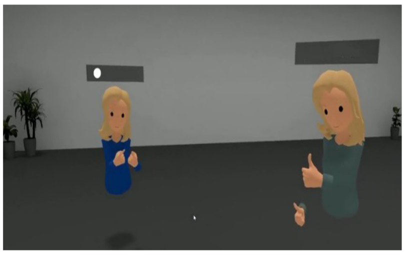
Stage III started with the second peer group supervision cycle in Zoom and social VR. Again, following the peer group supervision cycle, preservice teachers uploaded their guided reflective video statement that the teacher educator commented on. The following session served as a joint reflection and opportunity for feedback.

At the end of the semester, in **stage IV**, students presented their final version of their technology-integrated instructional designs based on sound reasoning and their pedagogical, technological, and content choices.

Social VR prototype

The social VR prototype, based on Unity 2019.4 and optimized for Microsoft Windows 10, offered a fully immersive seminar room. The Oculus Rift S, a Head Mounted Display, and a Laptop served as VR hardware. To avoid unnecessary distractions for the students, the virtual seminar room is kept clean and simple, offering room for collaboration and interaction.





Virtual instructions guide the user to set up the avatar and one's virtual representation. For avatar representation, a comic-alike abstract avatar is available. Outer appearances like the color of the upper body, gender, and name are customizable for the users. After entering the preferred avatar choice, representations' names appear over the avatar's head, visible for all participants. Before joining the group room, students can see their representation in a virtual mirror and train how to use the controller elements. For the facilitation of communication, a bright pulsating dot next to the speaker's name signals the speaker's turns. As the peer group supervision follows a fixed-timed structure, students can set a virtual stopwatch that runs for all participants visibly next to the presentation wall. On the wall, participants can see the peer group supervision procedure as a guideline.

Methodology and data collection

The convenience sample consisted of 17 preservice teachers (12 female and 5 male). The students had the opportunity to sign up voluntarily for the intervention. Data was collected using qualitative methods at three points of time:

1) After peer group, supervision I and II, preservice teachers had to upload guided reflective video statements on the online platform Flipgrid (n=17)
2) After peer group supervision II, qualitative half-structured group interviews were conducted. Groups were divided according to the medium they participated in, Zoom or social VR. (Zoom: n =5; social VR: n = 12)

Due to COVID-19 restrictions at the university, web-based social VR's participation required a stable internet connection and living no more than 10 km away from the university's location. That is why only a limited number of students could participate, as not all students met the requirements.

Regarding reflective video statements on Flipgrid, students watched an introductory video statement of the teacher educator who gave two main reflective prompts. The prompts follow Schön's (1987) understanding of "reflection on action" and were presented after each peer group supervision as follows:

a) Describe in short how you perceived peer group supervision.
b) Peer group supervision is supposed to offer the possibility of receiving new impulses and perspectives based on the exchange with your fellow students.
    - Which aspects of the peer group supervision did you perceive as goal-oriented or, more minor goal-oriented?
    - Which aspects of the video conferencing software ZOOM did you perceive as supportive or obstructive in the three phases (case presentation, question round, discussion/ reflection round?

Besides students' self-reflection, group interviews were conducted to consider also group reflection with the goal that group dynamics lead to a multidimensional understanding of group processes in Zoom and social VR.

The interview questions for the qualitative group interviews were derived from Tietze's peer group supervision, aiming to understand the nature of performing the consultation process twice in remote teacher education:

a) Compared to peer group supervision I in Zoom, how did you perceive the communication processes with your peers throughout the first phase, the presentation phase?
b) Compared to peer group supervision I in Zoom, how did you perceive the communication processes with your peers throughout the second phase, throughout question phase?
c) Compared to peer group supervision I in Zoom, how did you perceive the communication processes with your peers throughout the third phase, the discussion/ reflection phase?
d) Compared peer group supervision I, what technology's characteristics (Zoom and/ or social VR) did you, as a group, find supportive or obstructive throughout the consultation process?

The interviews were recorded, transcribed, and analyzed through qualitative content analysis (Mayring, 2015).They were coded using MAXQDA (Rädiker & Kuckartz, 2019). The following categories were determined deductively following the approach of Mayring (2015) and the four main features of peer group supervision according to Tietze (2010, 2013, 2018, 2021):

(1) Group size
(2) Design task
(3) Peer group supervision cycle
(4) Communication and collaboration with peers in reversible roles

4. Results

The results of the guided reflective video statements and qualitative group interviews conducted with preservice teachers will be presented systematically following the two cycles of peer group supervision (PGS 1 and 2), in stages two and three, and structured according to selected categories derived from Tietze's peer group supervision features (2010). The categories were adapted and extended according to research interest.

Categories	**Students' perceptions**	**Examples**
PGS I (Zoom)	***Reflective video statements on Flipgrid***	
(1) Group size	• Students perceived group sizes of three and four persons as interactive and helpful. • Limited timeframe of 90 minutes for each group did not allow more group participants.	*"Um, I can only speak from experience: the smaller the group, the more sense it makes. The more, um, effective you are in the discussion, I think." (Student K_PGS1)* *"Good group of three. Good preparation and different approaches were insightful." (Student K_PGS I_Video statements)*

		"I find it quite good in small groups. (...)I imagine the time limit to be a bit difficult, if one carries out this with colleagues at school in this way and then has only 10 minutes to look for possible solutions and so on... because I think this can be very difficult, especially when selecting the right approaches [...]." (Student J_PGS1)
(2) Design Task I	• Design task was complex and not easy to approach which led to some insecurities performing the task. • Task's complexity permitted individual approaches of how to perform the task.	*"First of all, I found it reassuring that my two group members didn't present a sample solution, we were struggling with how to approach the task." (Student H_PGS1)* *"There were three of us and we really had three completely different - that is, lesson designs and approaches - and that was kind of cool to see." (Student F_PGS1)*
(3) Peer group supervision cycle I	• All groups had difficulties sticking to the given structure and PGS's phases were mixed up. • Students asked questions at the presentation's exact point without waiting for the next phase to start. • Students that loosely followed a given structure perceived the questioning round as the most valuable part of peer group supervision, recognizing the gaps in their approaches to a solution. • Some students felt overwhelmed by peer group supervision. • In general, independently of the cycle's structure, most students perceived peer group supervision as practical and helpful.	*"Um, the only thing is that the question round had included the discussion round. If someone had questions about their own case, then it was actually immediately also - um - discussed in the discussion round [...]." (Student M_PGS1)* *"Well, I must admit that I didn't perceive the peer group supervision well at first, and to be honest, I was still a bit overwhelmed at the beginning and didn't know what to expect. And that's why I had a lot of questions and - but once we started, it got easier and easier. Or rather, you feel, um - a little more confident." (Student N_PGS1)* *" [...] the feedback from my three fellow students, in the group, was really very purposeful and very beneficial, too." (Student L_PGS1)*
(4) Communication and collaboration with peers in reversible roles (Zoom)	• Most students perceived communication as interactive, helpful, and supportive. • While most students thought their peers 'feedback helped the design's development, some felt the need for more expert feedback. • Regarding reversible roles, students recognized the roles' function as a facilitator for work processes. • For a successful peer group supervision, students realized that they must be open to criticism and that the team has to work together.	*"So, I think, mmm, the.... - yes, it's like always - the higher the expertise in some area, the better you can also um, help others or maybe express yourself." (Student J_PGS1)* *"Aspects that I found purposeful: above all, the joint agreement, and the distribution of roles. Just that you had this moderator and case 1, 2, 3, and 4. Um, took a lot of organizational work off at the beginning and, um, everyone knew roughly in which role he was and what he had to do." (Student M_PGS1)* *"Openness to criticism must be present. A*

	Regarding Zoom`s affordances: • The screen sharing option was numerously named as good support for collaborating throughout the process. When questions came up that students could not answer ad hoc, they shared their screens to share material or information to follow or help the group to find the information needed. • Using the breakout rooms without any supervision of teachers gave students the feeling of speaking openly and without pressure.	*functioning team is crucial for this." (Student J_PGS1)* *"Yes, regarding Zoom, what I actually thought was helpful about the Zoom application that we always had the working material visible, and we could easily switch from our presentation to the Internet using the screen sharing option. There, we had the syllabus displayed, which was actually super useful, because then we could always show directly what we referred to or what we had in mind." (Student P_PGS1)* *"I thought it was great in the way we did it: So completely unevaluated, just us students among ourselves. So that you could really exchange ideas and also - yes, try to help the others without being judged or feeling like you were being watched. I thought that was good - it was a very pleasant setting." (Student H_PGS1)*
PGS II (Zoom and social VR)	***Reflective video statements on Flipgrid and qualitative group interviews***	
(1) Group size	• Students favored groups of three to four for productive group work. • The students of a group of only two participants stated that this had no negative consequences for the process, as they had more time to talk about their two design concepts, but they would have wished for more perspectives and feedbacks.	*There were only two of us. On the one hand, that had advantages because we were able to have a good conversation and exchanged ideas...and helped each other. Um, this time, like last time, there were cool new ideas that helped me. Well, because we were only two people, it was just, yes.... Impulses or the perspective of two people." (Student F_PGS2_video statement)*
(2) Design Task II	• Students gained more confidence in creating their instructional design based on the seminar's theoretical basis.	*"I thought there was definitely clear learning progress. Both, um, with my concept on which I had continued to work, as well as with my two fellow students, with whom I was in the VR session. Um. Actually, the concept was more advanced and, of course, also more goal-oriented. Because we had all been through peer group supervision and reflection before, and there we still had had questions in our heads. I went into the peer group supervision and didn't really know what I was actually doing. That has definitely improved a lot. Of course, also through the session that we had again with you. Then in general I would like to say that I perceived the session as very pleasant." (Student H_PGS2_video statement)*
(3) Peer group supervision cycle II	a. In Zoom • Most students perceived the second PGS II as more structured.	*"In the first one, I had little idea what I was doing. In the second, I felt quite confident,*

	• They described the process as more coherent and goal-oriented as structure was followed more strictly. • Groups seemed to be more focused. • Students who took part via Zoom underlined the positive supervision's development regarding structure and workflow.	*and uh. I also have to admit that my fellow students… they have had a deeper understanding, uh, of the topic. Because this time we stuck to the concept. […] (Student N_PGS2_video statement)* *"I also think that since more and more theoretical knowledge was added over time, you also build up a different structure for yourself when you introduce things, so you just give more reasons, which is not the case the first time, […] but I honestly didn't understand it deeply: How to connect this and that? The first time it was just like I write something down and the second time it was already very well-founded and somehow also, yes for me already more structured from preparation on. (Student M_PGS2_interview)*
	b. In social VR • In contrast to participants in Zoom, students in social VR had no online platform to collaborate and had no chance to use written notes. Many preservice teachers that joined PGS II in social VR reported that the first phase, in contrast to PGS I in Zoom, was strictly performed as a presentation phase, and no one asked any questions. Reasons given for this were mainly the restricted communication cues in social VR. As students could not interpret speakers' turns because of missing gestures or facial expressions, they waited for the person presenting to end the talk before asking questions. Following this, boundaries of the subsequent two phases, question round, and discussion/reflection blurred and blended. Some students in each group reminded others of sticking to the given structure • In some groups, it was difficult to maintain an orderly process as several participants felt the need to take one or more breaks due to feeling exhausted wearing the VR headset. Several students said they realized very late that they needed a break as they focused intensely on the group work.	*"This also shifted the distribution of roles a bit - we didn't do it in such a way that everyone presented their topics first, but rather we went straight to the questions afterward - we more or less confronted the presentation with the questions. Otherwise, it would have been lost, and you had the feeling: When can I finally refer back to what she said? That's why after the first presentation we said: Ok, now the questions and discussion, and then the next person presents first. Before we all present, then do the big round of questions, and then the discussion." (Student I_PGS2_video statement)* *"I didn't even notice that I needed a break, but afterward I was completely exhausted for half an hour and couldn't do anything anymore. Although throughout the process I actually felt totally fine. Such a mandatory break I think would be really useful!" (Student G_PG2_interview)*
(4) Communication and collaboratio	a. In Zoom • Many students agreed on Zoom as a practical communication and collaboration	*" I think everything worked without any problems. It really was like a face-to-face live talk, with the chance to interrupt and engage*

n with peers in reversible roles (Zoom and social VR)	tool. One student emphasized its advantages compared to f2f seminars at university. • They agreed on the usefulness of the screen sharing and breakout session functions. • The positive effects of heterogeneous groups were that diverse perspectives were added to question and discussion rounds, pointing at unclear content. • However, one student felt it hard to put herself in the others' perspective and the age of their future students, and thus, it was challenging to give helpful advice. b. In Social VR • Participants perceived PGS II in social VR as intensive and close to reality. • Regarding communication and collaboration, many students had the impression that the interaction with others to be more "real" because of their avatar's representation. Also, they felt a sense of community. • One said he had a "first person effect" and could speak more freely than in Zoom. Interestingly, he had the feeling that in social VR his stuttering was minor, and he gained more stability because of the given feedback. • The reduced non-verbal cues in social VR led to positive and negative effects on the participants' communication. The preservice teachers perceived that everyone	*in speech, or, yes I think one understands more when everyone can freely speak and see each other." (Student N_PGS2_interview)* *"In general, in Zoom, I think the breakout rooms are super helpful because when I imagine how this works at Uni, this always takes time until one set up the workspace, this, however, is super relaxed, two klicks and you are in the group, and you can start right away to collaborate." (Student_D_PGS2_ interview)* *"And we also all had different, uh.... uh... types of schools. I actually thought it was interesting that we were able to see the designs of the other types of schools and also what challenges this meant for the others. I thought it was good that we didn't just saw one school-type design." (Student B_PGS2_video statement)* *"Although I would say that (...) I find it hard enough sometimes to put myself in my pupils' perspective, i.e. the ones I will be teaching in the defined framework of the 1st-4th grade, and it is quite good to exchange ideas with people who are in the same grade and not to exchange ideas with someone else of other grades." (Student F_PGS2_interview)* *"Mhm and also really one has the feeling that one is really sitting next to each other and I personally thought that was super, super cool. Um, also the consultation is in my opinion, compared to the last time, much, ... yes almost more intensive, somehow." (Student L_PGS2_video statement)* *"You somehow feel a bit closer, because you have a virtual person standing in front of you. Exactly, um, feels somehow a bit more real (laughter) than via ZOOM or similar, even though (in Zoom) you can also actually see each other." (Student E_PG2_video statement)* *" I think about Zoom you always have the problem that you see yourself and because it's first person in social VR, um, you don't have this problem and you can just talk much more freely with the other people. And um, also that you can manage it much better - no to stutter and everything. Um, in any case, VR has helped a lot as far as speaking freely is*

	in social VR complied strictly with conversation rules because of missing gestures or facial expressions. In addition to this, most of students focused more on the spoken word and the presented content. However, because of this, participants did not dare to ask questions at the corresponding parts. Without the opportunity of taking notes in social VR, consequently, they forgot the questions before having asked them. Thus, the question and discussion round were shorter than in PGS I, and some felt they missed meaningful opportunities of reflecting on their design. • In one group observed, seated positions of participants were incorrectly calibrated, and thus one student was a lot smaller virtually represented than the other two. The three stated that this was irritating for conversation. The lower-positioned student had the feeling that everyone was looking down on her while speaking. She felt uncomfortable and tried to stand up on her chair to become taller. • Some students remarked that they did not know their social VR peers and would like to have had a picture of the real person in mind. One added, though, that her peers' anonymity caused her feeling more secure in presenting her case and her questions, as she had not the feeling to say something stupid.	*concerned." (Student C_PG2_video statement)* *" In the presentation phase, it was very noticeable that there was a lot of monologue, which is not a bad thing. At least I didn't dare to ask questions back, because you don't see any gestures or facial expressions, and you don't notice whether the person is fully involved in his or her presentation and shouldn't be disturbed. And so one concentrated very strongly on listening and always thought: I'll keep the question in mind for now. But I guess a few questions were lost that we actually would have had for the second part." (Student I_PGS2_interview)* *"Well, it's uncomfortable for me to talk to you, because you're so above me." (Student K_PGS2_interview)* *"That made me a little sad, because I didn't know what they looked like, but they knew what they looked like. But otherwise - I also paid a lot of attention to the nodding of the head or the shaking, or the hands, actually (...) I think that I was perhaps a bit more confident in my presentation because I didn't look around all the time to see how people are looking or reacting. And I think I wouldn't necessarily have asked a lot of questions because I thought to myself at the moment, maybe that's a stupid question - but I didn't see how people were looking at the moment anyway, so I was more likely to ask them and say what I was thinking. (Student G_PGS2_video statement)*

5. Discussion and Implications

The results summarized above are subject to certain limitations. Regarding the samples of this exploratory study, it is essential to note that a convenience sample was used. Hence, against the background of the qualitative research approach and sampling method, the interviewees are not representative of their respective groups. Thus, the results may not apply to other preservice teachers in the same way. Furthermore, in this first exploratory study, the focus was on the perceived learning processes but not on the effects of the instructional design on the advancement of TPACK as meta-conceptual knowledge. This focus was chosen to better understand the effective implementation of video-based communication and a fully immersive learning environment for instructional design.

Concerning the further development of a pedagogical concept for initial teacher education, the results and the participatory observation of the study are leading to the following conclusions and pedagogical implications for an instructional design that promotes metacognitive learning processes in remote teaching and learning, taking into account preservice teachers' perceptions of the peer group supervision cycles in Zoom and social VR:

(1) Group size

To adapt the concept of peer group supervision to the seminar's conditions, the seminar duration was set to 90 minutes to give every participant the same amount of time to present a case or question. Consequently, no more than three to four participants (each 30 minutes supervision cycle) could form a group.

- ➔ Small size groups of up to a maximum of four people were perceived as productive and helpful. However, less than three participants would lead to less input and limited exchange of perspectives and opinions.

(2) Design task

At the beginning of introducing the design tasks and the new concept of peer group supervision, students faced multiple insecurities such as how to perform the complex task that allows multiple approaches and how to conduct peer group supervision. Moreover, students did not know each other and what to expect from their peers. However, this led to the initiation of questioning, reasoning, and reflective processes necessary to start creating their design. Students realized that there were several approaches of how to conduct the design task, observing their peers. For the students' support throughout this process, timely teacher feedback is essential. This way, insecurities related to their approaches can be reduced, and students become more confident to follow their design. As observed, the second design task was perceived as more manageable and clearer. Also, students seemed to be more focused and goal-oriented in working on their designs. After the second peer group supervision, reflection statements led to the assumption that students gained more confidence in presenting their design drafts and showed fewer insecurities. Based on the video statements and the interviews, peer and teacher feedback related to the designing process played a vital role.

- ➔ The design task and PGS cycles need a thorough introduction and a test run.
- ➔ Teacher's feedback should be placed after each PGS to clarify uncertainties.

(3) Peer group supervision cycle

As already mentioned, one can assume that preservice teachers gained more confidence throughout the design process from PGS I to PGS II and reported a more effective workflow in groups.

Participants who took part in Zoom in PGS I followed the PGS cycle's structure more consistently than in cycle one. Assumingly, students became more acquainted with the task, the cycle, their peers, and their design process. As a consequence, they felt more comfortable with interrupting their peers and risking the cycle's structure, but at the same time, this led to a lively exchange.

Preservice teachers that took part in the new social VR environment in PGS II had some difficulties in following the structure as intended. First, it took longer for them to start with the PGS cycle as they were distracted by social VR's surroundings and avatar representations. After starting the process, missing non-verbal communication cues led to uncertainties when to speak without interrupting peers. As a result, students listened more closely to each other's presentations and paid attention to gestures and body movements to interpret speakers' turns. On the one side, this might promote the cycle's consistency, as fewer interruptions will occur. On the other side, prompt questions and peer feedback might also be reduced and, thus, also its value for the learning process.

- ➔ For future PGS in social VR, it is recommendable to have more social VR sessions, so that students get used to the social VR surroundings, preventing too much time spent with VR's distractions.

(4) Communication and collaboration with peers in reversible roles

Concerning the implementation of digital collaboration media supported communication and collaboration throughout the PGS cycles, from students' perspective Zoom was beneficial for the group work in the PGS cycles. The screen sharing option and the breakout rooms resembled the peers' communication and collaboration style. Described as "realistic" and like "f2f" discussions, communication in Zoom was not perceived as disruptive. However, Zoom and the other collaboration platform (Miro) were the main communication tools throughout the semester and thus were frequently used. Through this repetitive media usage of the teacher educator as well as in group works, students internalized how to integrate the platforms in their PGS. In seminar sessions, when PGS did not take place student tutors and the teacher educator accompanied closely breakout sessions to support media usage and to give prompt feedback.

Communication and collaboration in social VR were not perceived as disruptive. However, communication processes were hindered or restricted due to missing non-verbal communication cues. Although the pulsating dot signaled the speaker's turn, it cost more concentration and cognitive load to interpret how group communication processes work. Within 90 minutes, the groups in social VR had to manage more cognitive load on top of managing the PGS cycle's structure. This could be facilitated with more support measures, adapting it to social VR's conditions. Such measures could be:

- ➔ more breaks throughout the PGS cycles signaled in VR by a watch
- ➔ implementation of features that allow note-taking, f.e. a virtual chat
- ➔ regular social VR sessions so that students get acquainted with VR hard-and software and thus communication and collaboration processes
- ➔ more than two PGS cycles to facilitate structure to be followed
- ➔ strengthening the sense of community with group tasks at the beginning of the semester
- ➔ flexibility in teacher presence and absence so that students have someone to turn to with questions but still mainly collaborate with peers

Simultaneously, the notions of the consequences of social VR's anonymity based on avatar representation might help students to be more self-confident, not fearing to be judged by others, or reducing stuttering and this way offering pedagogical potentials like promoting self-regulation and self-efficacy. This effect could be used, when groups are acquainted with each other and with the process, groups could be mixed up with changing avatar representations to create the anonymity effect and to promote change of perspectives that favors the reflecting process.

From a teacher educator's perspective, the implementation of peer group supervision in social VR requires thorough planning and designing of seminar sessions. The difficulty lies within finding the right balance of knowledge transfer, technology integration, and giving enough time for students to construct knowledge on their own without overwhelming them. Most importantly is the close teacher's support for students throughout the process. As the constructive learning process and the technology are perceived as new and connected to a sense of insecurity, students tend to struggle with the detachment of teacher-centered seminar sessions.

For future works, it will be necessary to investigate how preservice teachers' TPACK development takes place and how video-based communication and social VR might influence it.

The findings from this exploratory study are currently incorporated into the further development of pedagogical concepts using social VR in teacher education. The provision of the pedagogical approaches and the developed materials, as well as the social virtual environment as open-source, will contribute to the dissemination of social VR scenarios in different educational contexts.

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5.3 Conclusion

The aim of the third study was to further refine the pedagogical concept to promote the metacognitive learning processes of pre-service teachers and analyze how such teachers perceive their learning processes in social VR compared with video-based communication. The results showed that, although the refined pedagogical concept could be implemented successfully in general using a video conference system and social VR, some design principles should be further refined for the final study (see Section 6.2). Notably, students needed more breaks and more time to become accustomed to the communication processes in social VR than in video communication. However, the following advantages of using social VR were identified in the third study: In comparison with peer group supervision in Zoom, students reported that they felt closer to each other in social VR, and mainly because of social distancing regulations, they enjoyed being together (see Section 5.2). To harness these positive effects for knowledge co-construction (Garrison & Akyol, 2013) in social VR, group work and collaboration processes can be supported by integrating group tasks that strengthen the feeling of community (see Section 5.2). As the results also showed, repeating the peer group supervision cycle allowed students to become accustomed to the underlying communication and collaboration processes, and their lesson designs profited from more runs (see Section 5.2). Moreover, the three-part structure of peer group supervision allowed the flexibility for more breaks to be taken if needed and contributed to guiding students through the reflection and scaffolding processes (see Section 5.2). Although peer group supervision is highly learner-centered, the teacher plays a crucial role in giving support and feedback. The results showed that teacher feedback should be an integral part of each peer group supervision cycle to ensure the provision of expert knowledge (see Section 5.2).

Regarding group sizes, students agreed on no more than three to four participants in one peer group supervision (see Section 5.2). Further, essential insights were gained about the nature of the design task. Its complexity is crucial in ensuring constructive exchange between students and thus a successful condition for the systematic construction of their lesson design (see Section 5.2).

Although still open to further development at this stage of the research and development cycle, the pedagogical concept seemed to be robust for the final evaluation. Therefore, as a next step, the effect of the pedagogical concept on pre-service teachers' TPACK development was investigated and evaluated (see Section 6.2).

6. Mapping Pre-service Teachers' TPACK Development Using a Social Virtual Reality and Video Conferencing System

6.1 Aims of Study 4

In the first two studies carried out for the current research, contextual factors for a pedagogical concept to foster the TPACK of pre-service teachers in social VR were analyzed and explored by implementing a prototypical pedagogical concept to promote such TPACK using social VR on campus (Sections 3.2 and 4.2). In the third study, the pedagogical concept was refined by integrating further design principles and shifting from the lab setting to distributed teaching and learning processes to compare the use of social VR and a video-conferencing system (see Section 5.2). The aim of Study 4 was to evaluate how the refined pedagogical concept can foster pre-service teachers' TPACK as metaconceptual awareness using social VR. Based on the insights gained from previous studies (Sections 3.2 to 5.2), the design of the pedagogical concept to promote TPACK as a metaconceptual awareness was refined and took the following design principles into account:

- Presentation of a complex and authentic design task
- Learner-centered learning activities
- Social learning processes
- Flipped classroom principles
- Action orientation
- Leaving space for support and breaks
- Scaffolding, reflection, and problem solving
- Content alignment to TPACK
- Teacher's feedback

As in Study 3, the implementation of the pedagogical concept in social VR was compared with use of a video-conferencing system. Thus, Study 4 addressed the following research question for the evaluation of the achievement of the pedagogical concept's objective:

- How did pre-service teachers' TPACK develop when they used a social VR learning environment prototype compared with a video-conferencing platform throughout the semester?

Accordingly, Study 4 aimed to enable consolidation of the pedagogical concept and its design principles in a summative evaluation with regard to Euler's (2014) design cycle.

6.2 Study 4

Innovate Learning Summit Online 2021 - , United States, November 9-11, 2021

Mapping pre-service teachers' TPACK development using a social virtual reality and a video-conferencing system

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Abstract: Social VR's characteristics, by offering authentic learning environments that enable interaction remotely and synchronously and permit learning experiences that affect learners in a multi-sensory way, offer great potential for teaching and learning processes. However, concerning its use to promote pre-service teachers' TPACK in initial teacher education, there remains a research desideratum. In this context, this exploratory study addressed the following research question: How did pre-service teachers' TPACK develop using a social VR learning environment prototype in comparison to a video-conferencing platform throughout a semester? Following a design-based research approach, an action-oriented pedagogical concept for teaching and learning in social VR was designed and implemented for initial teacher education at a German university with a convenience sample of 14 participants. The lesson plans were collected and analyzed with the help of Epistemic Network Analysis (Shaffer, 2017) at three points of time during the semester and the GATI reflection process (Krauskopf et al., 2018). Further, 14 GATI diagrams gave insights into pre-service teachers' self-estimated TPACK. As the results indicate, pre-service students constructed more complex mental models of TPACK in social VR compared to the video-conferencing platform, indicating that more interrelations between knowledge domains could be constructed by planning and designing VR-integrated lesson plans.

Introduction

The sound integration of technology into classrooms involves multiple decisions from pre-service teachers. They need to 1) plan and design appropriate learning activities and scenarios for teaching with technology; 2) choose digital media and content accordingly; 3) embed them in the pedagogical concept that supports their choice; and 4) decide when and how to use it (Kramarski & Michalsky, 2010). In initial teacher education, it is thus vital to promote pre-service teachers' media pedagogical competencies, which include the competent use of the quickly developing social VR platforms, whose classroom use differs from that of other digital media in terms of resources and implementation. Therefore, to prepare students to meet these requirements, pedagogical concepts need to be developed, which include learning prerequisites, learning objectives, teaching and learning activities, technology, content, and social forms (Tulodziecki et al., 2021). There is, however, still a research desideratum on how to promote pre-service teachers' Technological Pedagogical Content Knowledge (TPACK) using social VR platforms in initial teacher education. In this context, this exploratory research study focused on promoting pre-service teachers' TPACK by aiming to answer the following research question:

RQ1: How did pre-service teachers' TPACK develop using a social VR learning environment prototype compared to using a video-conferencing system?

Literature Review

TPACK: Development and Measurement

A variety of models exist to describe the media-related competencies and knowledge of pre-service teachers (for an overview, see Tiede (2020)). Based on Shulman's (1986) research, the conceptual framework TPACK (Mishra & Koehler, 2006) is internationally well known for addressing the multifaceted implications of the effective integration of technology into learning scenarios. In addition to the three core knowledge domains—pedagogical, technological, and content knowledge (PK, TK, CK)—the framework comprises their intersectional components: technological pedagogical knowledge (TPK), technological content knowledge (TCK), pedagogical content knowledge (PCK), and technological pedagogical content knowledge (TPACK) (Koehler & Mishra, 2008).

Different definitions of the individual knowledge domains exist (13 definitions for TCK and 89 for the central construct TPACK) (Cox, 2008). However, the interrelation or the distinction of the domains and their overlaps or their relation to external context aspects remains unclear (Mishra, 2019). From 2009, a discussion of the two views concerning the quality and interplay of the seven knowledge domains evolved. According to the integrative view, "high levels of TPCK will be constituted by high levels of TPK, TCK, PCK, TK, PK, and CK." In contrast, in the transformative view, "TPCK cannot simply be accounted for by summing all other TPACK components, but rather it is a distinct form of knowledge which transforms beyond the components at its base" (Schmid et al., 2020). In other words, according to the integrative view, TPACK originates from the seven knowledge domains and is a part of them, whereas, according to the transformative view, TPACK forms a whole new unique body of knowledge.

Krauskopf et al. (2012, 2018) critically approached the transformative view with their coherent theory of TPACK as a meta-conceptual awareness. Following the transformative view, the theory assumes that the TPACK framework also comprises metacognitive learning processes involving higher-order thinking. Thus, according to the authors, the TPACK model is a multi-level structure, assuming a two-level transformation to achieve TPACK. They characterize the first level as the construction of mental models that occurs by the conversion of knowledge of the basic knowledge domains (TK, PK, CK) into knowledge of the overlapping subdomains (PCK, TPK, TCK). Further, on the second level, the transformed knowledge domain of TPCK represents the meta-conceptual awareness of the demands of designing a lesson with technology (Krauskopf et al., 2018). This however leaves unresolved how the knowledge subdomains support the construction of mental models and how they are transformed from level one to level two.

In addition to the different interpretations and the rise of numerous extended versions of the TPACK framework, Chai et al. (2010) highlighted the difficulty of measuring the TPACK of inexperienced pre-service teachers: doing so might lead to biased results based on their differing perceptions of the seven knowledge domains. Moreover, as further developments have also demonstrated, more variables, such as demographic data, teacher beliefs, self-perception, confidence, and self-efficacy, should be measured by TPACK's instruments (Chai et al., 2010). This led to the assumption that different types of TPACK profiles of pre-and in-service teachers should be considered when assessing TPACK (cf. Koh & Chai, 2014; Koh, Wooh, & Lim, 2013; Shih & Chuang, 2012).

Furthermore, research has focused on the TPACK construct's validity and reliability, its implementation in learning and teaching scenarios, or its impact on learning processes and teaching practices (cf. Abbitt, 2011).

According to Su and Foulger (2020), there has been "a shift over time, from quantitatively examining teachers' professed TPACK to qualitatively investigating teachers' enacted TPACK." In addition, to posit a more holistic view of TPACK, researchers moved away from using only one measurement method, turning instead to mixed methods approaches or combining different measuring instruments to balance efficiency, reliability, validity, or subjectivity (cf. Chai, Koh, & Tsai, 2011). Wang et al. (2019) identified mainly five methods to measure TPACK development in pre-service teacher education: 1) self-report measures (i.e., Likert scale, cf. Schmidt (2009), Koh, & Tsai (2011)); 2) open-ended questionnaires (i.e., written responses to questionnaire questions); 3) performance assessments (i.e., rubrics, performance tasks, created artifacts, lesson plan, content analysis, and reflections); 4) interviews (i.e., oral responses), and 5) observations (i.e., taking field notes, video-recording lessons).

The Graphical Assessment of TPACK instrument (GATI) was tested by Krauskopf et al. (2018), following their transformative perspective of TPACK, in their proof-of-concept study to visualize teachers' professional knowledge and prompt self-reflection through meta-conceptual awareness. Moreover, they considered the study a test of GATI's applicability as a scaffold for teachers' professional learning concerning technological integration.

In a three-part process, two in-service teachers participated in the GATI process. First, they completed a self-report questionnaire adapted from Schmidt et al. (2009) using a five-point Likert scale. After, with the help of a template with a set of six circles sized for each of the three knowledge areas of TPACK, they were asked to reflect on their current professional knowledge in each of the three domains. Further, they were asked to rearrange the circles in the way they perceived how the domains were interrelated, constructing a Venn diagram. They had to explain how they decided the size of each circle and the amount of overlap. After, they had to create and explain a second Venn diagram, representing the professional knowledge they wanted to achieve. Concluding that the GATI reflection process supports teachers in reflecting on their professional knowledge, the authors acknowledged GATI's potential as a measurement instrument (Krauskopf et al., 2018).

In contrast to a self-assessment survey, during the GATI process, the participants could state their understanding of what comprises TPACK and whether and how knowledge domains overlap. However, due to the participants' subjective view on TPACK, comparability of results is difficult. On the measurement of TPACK's development to explore the validity of the different domain sizes and overlaps and combine them with quantitative research methods, the authors noted the need for further research.

Another possible and valuable technique to map and trace TPACK development, because it can model the relationships between the seven knowledge domains and how pre-service teachers' knowledge domains transform over time, is Epistemic Network Analysis (ENA) (Shaffer, 2012, 2016, 2017). As the structure of connections in the data is considered most important in the analysis, the following is assumed: (1) that it is possible to systematically identify a set of meaningful features in the data (codes); (2) that the data has local structure (conversations); and (3) that an essential feature of the data is how the codes are connected within conversations (Shaffer, 2017; Shaffer, Collier, & Ruis, 2016; Shaffer & Ruis, 2017). ENA models the connections between codes by quantifying the co-occurrence of codes within conversations or texts, producing a weighted network of co-occurrences along with associated visualizations for each unit of analysis in the data. ENA analyses all the networks simultaneously, producing a set of networks that can be compared visually and statistically.

Multimedia Learning Environments for Situated Learning and Teaching

During the COVID-19 pandemic, remote teaching and learning processes relied on digital media, allowing remote lessons to be taught as close to "real" face-to-face classroom scenarios as possible. For teacher educators in higher education, this meant pursuing learning objectives by effectively combining the positives of f2f teaching and learning with online learning scenarios.

Learning environments should embed the learning content into a situation-specific context (Dawley et al., 2014) and allow learners to establish connections to their prior experiences and their previous knowledge (Tulodziecki et al. 2021). Based on the supposition that the situation and context of the learning process determine the conditions in which knowledge is later applied (Jonassen, 1992), learning activities should comprise authentic application examples that leave enough room for self-determined learning processes (Reigeluth, 2015).

Moreover, based on the assumption that the situation and context of the learning process determine the conditions in which the knowledge is later applied (Jonassen, 1992), learning activities should comprise authentic application examples that leave enough room for the learner to have maximum self-control throughout the learning process.

Furthermore, since knowledge construction occurs through a cooperative exchange with others through co-construction (Reusser, 2001), teaching-learning activities should take social processes into account and provide space for them. However, when teaching and learning shifts from f2f to remote learning environments and the social presence of participants must be sustained by digital media, this becomes especially challenging. Social presence, as Garrison et al. (2013) emphasized, is paramount for collaborative and constructive learning environments.

During the pandemic, educational institutions had to rely on well-established web conferencing tools such as ZOOM, Big Blue Button, Microsoft Teams, or Cisco Webex. Features such as 2D-video exchange, screen sharing, and breakout rooms for group activities support teaching and learning processes. Web conferencing tools, Hacker et al. (2020) concluded, make participants feel that they are virtually together with others and thus create a social co-presence.

However, video-conferencing is also known for specific deficits in terms of social interactions regarding synchronousness, non-verbal cues, physical proximity, spatial cohesiveness (Abfalter et al., 2012), and processing (Ferran & Watts, 2008). For example, consumer-grade systems lack proper support for well-working eye contact; they reduce the shared spatial and hence referential space to little 2D images of the participants. Overall, they do not directly support the necessary social signals, such as eye contact, joint attention, or grouping (Roth et al., 2018).

In contrast, virtual, augmented, and mixed reality (VR, AR, MR; XR for short) can convey such signals, increasing user embodiment, co-presence, and the possibility of interaction (Latoschik et al., 2019). On this basis, studies have elaborated VR's suitability for situated and constructive learning approaches. Johnson-Glenberg (2020), for example, based on Woolfolk (2007), highlighted VR's versatility: it allows "complex, realistic and relevant learning environments," the "support of multiple perspectives and representations of content" as well as agency and ownership of one's learning (pp.7-8). In particular, the opportunity to create "a "complex, realistic and relevant learning environment" that in real-life learning scenarios would be too expensive, unethical, dangerous, or not possible harbors the high potential of creating learning scenarios according to situated learning (cf. Hellriegel & Čubela, 2018). Even complex and abstract concepts and facts that are difficult to visualize in the conventional sense can be concretely illustrated using VR (Hellriegel & Čubela, 2018). This way, knowledge acquirement will take place in the context or environment to which the knowledge will be applied. However, studies that have assessed and evaluated VR's effects on situated learning are rare.

Having implemented a social VR learning environment prototype, Ripka et al. (2021) reported its supporting but also hindering effects on situated and cooperative learning processes in initial teacher education. For example, social VR's anonymity based on avatar representation favored students' self-confidence, allowing them to be not fearful of being judged by others. The participants' insecurities and stuttering were also reduced, which led to pedagogical opportunities for promoting self-regulation and self-efficacy Moreover, social VR's realistic communication and interactions enabled a sense of community, which supported the social learning processes (Ripka et al., 2021).

However, the authors highlighted the difficulties concerning social VR's integration into seminar concepts. For example, missing non-verbal cues, visual stimuli, and disruptive communications may result in cognitive overload, influencing the success of learning processes in social VR. Makransky et al. (2019), for example, assessed the influence of immersive technologies on learning outcomes and concluded that students were overloaded during learning processes when they learned in immersive VR. For instructional designers of VR-integrated lessons, this means finding the right balance in offering a variety of design principles to promote the respective competencies in a situated learning scenario and avoiding cognitive overloading students.

Research Methodology

This study aimed to explore how pre-service teachers develop their TPACK using an action-oriented pedagogical concept using a prototypical, fully immersive social VR learning environment compared to using a video-conferencing software. To this end, we used a design-based research methodology (Tulodziecki et al., 2013).

Study Design

Pedagogical Concept

The pedagogical concept is to promote pre-service teachers' TPACK development as a meta-cognitive awareness (Krauskopf et al., 2018). Regarding previous research (Ripka et al., 2021), the following design principles were considered goal-oriented:

- Following the principles of action-oriented teaching and learning by design (Tulodziecki et al., 2017) and a learning-by-design approach (Koehler & Mishra, 2005), the pre-service teachers get a complex task to evolve a lesson design on their own throughout the teaching and learning process. The design task is to develop a VR-integrated lesson design for teaching and learning scenarios according to primary, secondary, or special education curriculums in a constructive and iterative design process.
- The progression of the pedagogical concept follows a consecutive structure that comprises learning and teaching scenarios based on action- and development-oriented teaching following an ideal-typical structure of eight phases (Tulodziecki et al., 2017). These involved introducing and discussing the scenarios, agreeing on learning goals and their meaningfulness, planning activities, learning about important theoretical and empirical foundations for VR-integrated lesson designs, designing, presenting and discussing own lesson designs, and reflecting on the learning content and process.
- To promote the iterative development process and reflective practice, the pre-service teachers participate in peer-group supervisions following a pre-structured consulting cycle (Tietze 2013, 2018; Ripka et al., 2021). In groups of three, the students present their lesson design or a related question, a problem, or a case. They take three roles throughout the consultation cycle to coordinate and facilitate the communication: the advice seeker, the advice-giver, and the moderator. The teacher educator is not present, but is a facilitator, who monitors the processes and intervenes when necessary. The consultation process comprises three main phases of approximately 10 minutes:
  a. The advice seekers present their case. The others listen and do not interfere.
  b. The advice-givers pose questions to clarify the stated case and information.
  c. The advisers offer ideas, information, or concepts that might help. Finally, a discussion or joint reflection takes place.
  After each peer group supervision, the teacher educator offers support and inquiries to tackle unanswered questions or prevent misunderstandings.
- To enhance reflection and metacognitive awareness (Krauskopf et al., 2018; Tietze 2013, 2018), the pre-service teachers document and illustrate their lesson designs' development and reflections in a portfolio. With the insights gained from each seminar session, the students revise their portfolios continuously and integrate the consultation advice they get during peer group supervision into their lesson designs. They hand in revised versions at five points throughout the semester.

Implementation

The implementation of the pedagogical concept took place in two groups of 12 students, each in an advanced media pedagogical seminar for pre-service teachers in initial teacher education at a German university during the summer semester from April until July 2021. Following and integrating the design principles explained above, the following structure was derived:

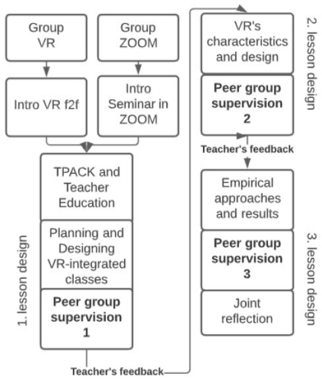

Figure 1 The Derived Structure of the Pedagogical Concept

Social VR Learning Environment and Group Video-Conferencing System

Based on Unity 2019.4 and optimized for Microsoft Windows 10, the social VR prototype offered a fully immersive seminar room. The students and the teacher educator used the Oculus Rift S, a head-mounted display, and a laptop as VR hardware. The virtual seminar room was clean and simple to avoid unnecessary distractions for students and offered a space for collaboration and interaction (Ripka et al., 2021).

Figure 2 Social VR Learning Environment

The VR system allows users to personalize their own stylized avatars and select characteristics such as skin color, gender, and torso color. After a short tutorial and introduction to the software's main features, the participants can see their avatars' representation in a virtual mirror. When participants speak, a pulsating dot appears next to their names regarding communication facilitation. Further integrated features, such as a virtual stopwatch, support learning activities. All the participants can activate a control board with one click that offers the possibility of changing presentation mode, muting microphones, and changing position assignments for the avatars in the room. A voice memo function allows the recording of short notes during seminar sessions. In addition, students can take screenshots of the presented screen at the time of recording so that they can revise at home their notes set into the proper context. Compared to the students, teacher educators have additional options. They can switch between the different group rooms (A–D) and activate or deactivate 3D-based group tasks in and outside group rooms.

For its video-conferencing system, this study used ZOOM Version 5.7.6 (1320). Due to COVID-19 regulations, remote teaching at university took place via ZOOM, and the students are acquainted with its primary functions, including screen sharing, collaborating on the virtual whiteboard, and moving between breakout rooms.

Methodology, Sample, and Data Collection

The study was conducted during the summer semester of 2021 at a German university, from April until July 2021. A total of 14 pre-service teachers participated voluntarily in all rounds of data collection. The convenience sample of the group using ViLeArn consisted of (n_1=7; 6 females, 1 male), and the group using ZOOM consisted of (n_2=7, 5 females, 2 males).

The seminars' content did not differ. The students of the VR group received a one-to-one introduction about the VR hard- and software in compliance with social distancing rules. The VR hardware was cleaned and disinfected before and after the seminar. However, due to COVID 19 restrictions, the ZOOM group could not test their VR hard-and software in a face-to-face workshop, but they received a 30-minute introduction to VR hardware via ZOOM.

Data were collected qualitatively in a pre-and post-test study design. The pre-service teachers' lesson designs were coded and evaluated with ENA (Shaffer, 2006, 2007, 2012) at three stages throughout the semester. For a detailed interpretation of the ENA results, the students were asked to describe and estimate their current state of TPACK with the help of the GATI reflection procedure according to an adapted version of Krauskopf et al. (2018) at the beginning and the end of the semester. The data collection is described in more detail in the following section.

a.) Portfolios and ENA

To make TPACK development visible as learning artifacts, the students revised and redesigned their lesson plans iteratively in a portfolio. Thus, at the beginning of the semester, the pre-service teachers got a situated complex task:

You are in teacher training at school, and your supervising teacher asks you to design a lesson with VR for a grade of your choice. Your final version of the lesson design should answer the following guiding questions and be able to justify your respective decision:

- *For which target group is the concept intended?*
- *Which teaching-learning theoretical approaches does your concept refer to?*
- *To which curricular goals are the teaching and learning processes aligned?*
- *Which media competencies are promoted by your concept?*
- *How do you use the VR medium in the classroom, and what significance does it play in the implementation of the teaching and learning processes?*
- *Which features of the VR medium support teaching-learning activities?*
- *What opportunities and challenges did you face while planning and designing your teaching concept through VR?* (own translation).

As described above, the students integrated the insights into the seminar content and the consultation advice from peer group supervision into their lesson designs. The versions at three points of time of each student were collected and used for ENA: (1) the beginning of the semester, (2) after the second peer group supervision, and (3) the final version.

To analyze TPACK development, we applied ENA (Shaffer, 2017; Shaffer, Collier, & Ruis, 2016; Shaffer & Ruis, 2017) to our data using the ENA1.7.0 (Marquart, Swiecki, et al., 2018) Web Tool (version 1.7.0) (Marquart et al., 2018).

The earlier test runs with ENA using the seven TPACK knowledge domains as codes showed that the demarcations between the individual knowledge domains are not sufficiently clear-cut for ENA, which is why a statement about the development and quality of the (meta-) cognitive processes and thus also about the respective references would not have been reliable and valid. Given that cognitive processes and developments are to be mapped with ENA, the TPACK codes set must also take into account not just knowledge states but also processes. Hence, we combined the seven knowledge dimensions (Wiesner & Schreiner, 2020) with process dimensions (Anderson et al., 2001). According to Anderson et al. (2001), the four knowledge dimensions differentiate between declarative (factual), conceptual, procedural, and metacognitive knowledge, and they build on each other in the sense of a continuum from the concrete to the abstract. Since we assumed that TPACK as meta-cognitive awareness can be achieved through two levels of transformations of the knowledge domains by building mental models, we included the following codes:

Table 1

Overview Code Categories for Coding Process of Portfolios

Knowledge Dimension	Level of transformation	Knowledge Domains	Example Code Category PK
Declarative Knowledge	1. Level transformation (TK, PK, CK)	TK1	*Pre-service teachers can summarize and select the basic teaching-learning theories according to self-selected criteria. (PK1)*
		PK1	
		CK1	
	2. Level transformation (TPK, PCK)	TPK1	
		PCK1	
		TCK1	
Conceptual Knowledge	1. Level transformation (TK, PK, CK)	TK2	*Pre-service teachers can recognize and categorize the basic teaching-learning theories according to self-selected criteria. (PK2)*
		PK2	
		CK2	
	2. Level transformation (TPK, PCK)	TPK2	
		PCK2	
		TCK2	
Procedural Knowledge	1. Level transformation (TK, PK, CK)	TK3	*Pre-service teachers can explain and evaluate the basic teaching-learning theories according to self-selected criteria. (PK3)*
		PK3	
		CK3	
	2. Level transformation (TPK, PCK)	TPK3	
		PCK 3	
		TCK3	
Metacognitive Knowledge	1. Level transformation (TK, PK, CK)	TK4	*Pre-service teachers can identify and reflect on the basic teaching-learning theories according to self-selected criteria. (PK4)*
		PK4	
		CK4	
	2. Level transformation (TPK, PCK)	TPK4	
		PCK4	
		TCK4	

We defined the units of analysis as all lines of data associated with the comparison plots between group VR and group ZOOM subset by the group type (for data comparison: VR 01, ZOOM 02), point of time (01, 02, 03), number of documents (f.e 2030303), and the associated peer group of the supervision cycle (f.e 203). In addition, we defined the references made in the portfolios as all lines of data associated with a single value of the semantical relation to all TPACK codes.

The ENA algorithm uses a moving window to construct a network model for each line in the data, showing how codes in the current line are connected to codes that occur within the current temporal context, defined as four lines (each line plus the three previous lines) within a given reference to TPACK codes. The resulting networks are aggregated for all lines for each unit of analysis in the model. In this model, we aggregated the networks using a binary summation in which the networks for a given line reflect the presence or absence of the co-occurrence of each pair of codes.

The ENA model normalized the networks for all units of analysis before they were subjected to a dimensional reduction, which accounts that different units of analysis may have different amounts of coded lines in the data. For the dimensional reduction, we used a singular value decomposition, which produces orthogonal dimensions that maximize the variance explained by each dimension (Shaffer et al., 2016). For a more detailed explanation of mathematics, see Sullivan et al. (2017).

The networks were visualized using network graphs, where nodes correspond to the codes and edges reflect the relative frequency of co-occurrence, or connection, between two codes. This results in two coordinated representations for each unit of analysis: (1) a plotted point, representing the location of that unit's network in the low-dimensional projected space, and (2) a weighted network graph. The positions of the network graph nodes are fixed, and those positions are determined by an optimization routine that minimizes the difference between the plotted points and their corresponding network centroids.

Data were analyzed and coded by the first and second coders. The first coder set the codes according to their appearance in the portfolios. The codes were set in order of sense units. The second coder then did the same, and after a final discussion between the first and second coders, the references of the individual codes to each other were set.

To go beyond the interrelations drawn between the knowledge domains, we considered the occurrence of codes in the respective group.

b.) TPACK GATI Diagram

To visualize pre-service teachers' estimation of their TPACK development, students were asked to reflect on their individual GATI diagram in their portfolio at the beginning and the end of the seminar. We implemented an adaptation of the GATI procedure of Krauskopf et al. (2018) and used the reflective prompts for the "current status "of TPACK and the GATI template to select the size of the knowledge bases (size 1–6). The task required that the students 1) describe the individual areas of knowledge, assuming that the smallest circles represent the knowledge of a non-expert and the largest that of an expert; and 2) put them in relation to each other and reflect on their Venn diagrams in writing.

Results

The results of the portfolios' ENA and the GATI diagrams are presented systematically following the assumed two-level transformation processes to achieve TPACK as a meta-conceptual awareness through constructing mental models (1st and 2nd level of transformation). To answer the research question of how pre-service teachers' TPACK developed throughout the semester, this study focused on three main aspects:

- The development of each group's ENA network considering the connections' and nodes' weights at the three time points
- The isolated development of the references made between the three points of time
- The frequency of codes of each group without considering the references made between the knowledge domains

First-level Transformation of the Basic Knowledge Domains TK, PK, CK into Mental Models (TPK, PCK, TCK)

a.) ENA Networks

For the interpretation of the results, the ENA networks' nodes and connections with the minimal node's edge weight of 0.15 and scale edge weight of 0.5 were considered. This means that, even though the codes were set and counted for ENA, only those would be displayed that reoccur often enough to create a node and related connections in the network with the respective weight. The smaller the set edge weight, the more connections are involved, even if their reoccurrence is not meaningful enough for interpretation. That is why the edge weights were adapted to extract higher reoccurrences of the knowledge domain's connections. Therefore, the presentation of the results is based on the graphs of the ENA networks.

In Figure 1, the ENA network shows the positions of both groups in correlation to each other. The dots of each group (group VR: blue (1), ZOOM: red (0)) indicate the projected point of each student (1–7), and the squares represent the average of the confidence interval along both dimensions.

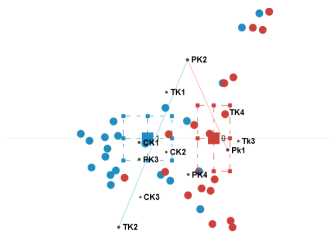

Figure 3: The ENA network of both groups; point of time 03 (blue = VR; red = ZOOM)

The ENA networks of both groups show an increase in connections and, thus, a thicker compound in color between the knowledge domains. As figures 3, 4abc and 5abc indicate, the connection between PK1 and PK2 is in both groups a reoccurring and strengthening connection across all points in time. Whereas group VR's network indicates stronger connections drawn between PK2 and TK2 at all time points, ZOOM's network only shows at the first and second point of time (Figure 4a, b) the inclusion of the knowledge domain TK3 connected to PK2. In general, the ZOOM group's network displays the repetitive connections between PK1and PK2 and

PK3 knowledge domains that increases from 01 to 03. A further slight connection is implied to CK1 at point of time 02. Moreover, the network indicates the central starting point PK1 for connections made (PK1-PK2, PK1-PK3-PK1-PK4), creating a star-like ENA network representation. In comparison, at point of time 02, the VR group established additional links between TK1-CK1-PK3 and PK3-PK2, resulting in more interrelations between knowledge domains at point of time 02 and 03 (figures 4bc and 5bc).

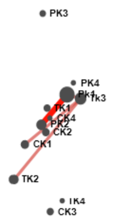

Figure 4a: Group ZOOM, time point 01

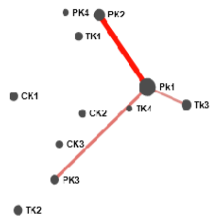

Figure 4b: Group ZOOM, time point 02

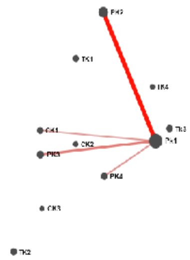

Figure 4c: Group ZOOM, time point 03

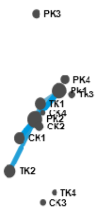

Figure 5a: Group VR, time point 01

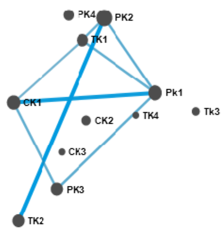

Figure 5b: Group VR, time point 02

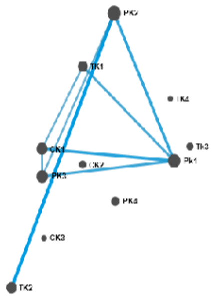

Figure 5c: Group VR, time point 03

In a further step, to back up the interpretation of the ENA networks, including all codes of all portfolios, the codes that were added from the point of time 01 to 02 and from 02 to 03 were extracted and analyzed, so that only the newly created connections would be displayed:

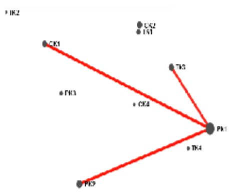

Figure 6a: Group ZOOM, time point 01

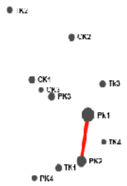

Figure 6b: Group ZOOM, time point 02

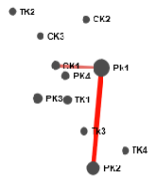

Figure 6c: Group ZOOM, time point 03

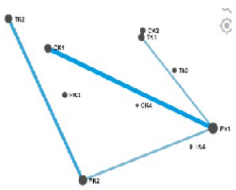

Figure 7a: Group VR, time point 01

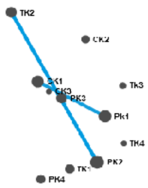

Figure 7b: Group VR, time point 02

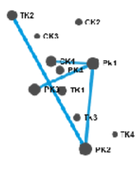

Figure 7c: Group VR, time point 03

In addition, the frequency of the reoccurrence of codes was counted and compared between the groups:

Codes	Point of Time	TK1	TK2	TK3	TK4	PK1	PK2	PK3	PK4	CK1	CK2	CK3	CK4
VR	**1**	14	17	6	2	27	22	11	6	9	7	1	0
	2	21	25	14	8	37	38	39	20	25	13	9	2
	3	34	48	34	14	66	58	73	27	34	18	9	0
		69	**90**	**54**	**24**	**130**	**118**	**123**	**53**	**68**	**38**	**19**	**2**
Zoom	**1**	8	4	4	2	25	16	8	1	7	1	2	0
	2	20	7	7	5	46	40	50	16	17	5	1	1
	3	29	17	17	16	64	57	77	30	12	7	5	2
		57	**28**	**25**	**23**	**135**	**113**	**135**	**47**	**36**	**13**	**8**	**3**

The summary of all the three sets of data indicate the following developments of codes and their interrelations:

In both groups, there was nearly no difference between the knowledge domains' development of PK1, PK2, PK3, and PK4. However, the ZOOM group made the most progress between time points 01 and 02, whereas the VR group made more progress in the PK areas after the second time point. The further divergent developments are as follows:

1.) Group ZOOM:
- The strongest connection was built between PK1-PK2. Studying the data of the ZOOM group, it was noticeable that the references were mainly formed in the PK areas. Additionally, all the references originated in PK1: PK1-PK2, PK1-CK1, PK1-PK3, and PK1-PK4.
- The highest number of codes represented in the ZOOM group was limited to the PK areas PK1, PK2, PK3, and PK4.

2.) Group VR:
- The strongest connection was between PK2-TK2. However, the ENA networks indicate the development of further connections between PK1-CK1 at point of time 01. Furthermore, at the last observed time 03, students made additional connections between the knowledge domains PK3, resulting in an ENA network displaying the interrelations between TK1-PK1-CK1 and PK1-PK2-TK2 PK1-PK3, PK3-CK1, and CK1-PK1.
- The sum of codes within the TK knowledge domains suggests that TK2 and TK3 were applied more often than in the other group. Further, CK1 and CK2 appeared more frequently.

b.) GATI Diagrams

In their GATI diagrams, the students of both groups described gains in their respective knowledge areas. All of them reported an increase of technical knowledge in the form of at least one bigger circle size (cf. figures 8 and 9).

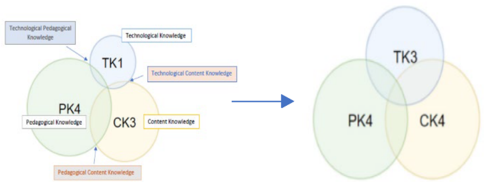

Figure 8: GATI Diagram Student H, VR, time point 01 and 03

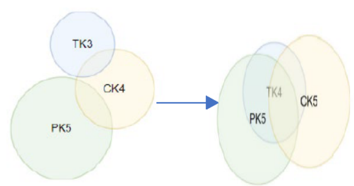

Figure 9: GATI Diagram Student D, ZOOM, time point 01 and 03

The groups differed, however, in the focus of their remarks. The VR group mainly described the growth and connections of TK and CK knowledge, while the ZOOM group mainly referred to pedagogical knowledge.

Figure 10: GATI Diagram, Student B, VR, time point 01 and 03

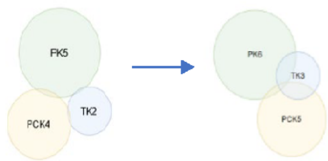

Figure 11: GATI Diagram, ZOOM, Student E, time point 01 and 03

Second-Level Transformation of Mental Models TPK, PCK, TCK to TPACK

a.) ENA Networks

To represent the existing mental models, their development, and relations to each other in students' lessons plans, we repeated the same procedure for the knowledge domains TPK, PCK, and TCK. As TCK was not coded, the result representation was focused on TPK and TCK.

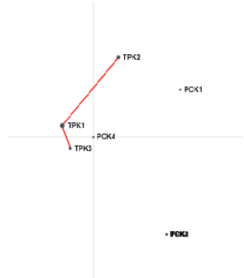

Figure 12a: Group ZOOM, time point 01

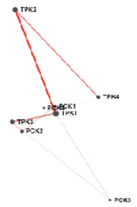

Figure 12b: Group ZOOM, time point 02

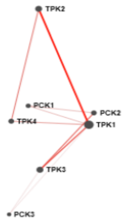

Figure 12c: Group ZOOM, time point 03

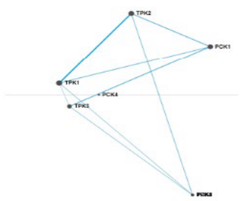

Figure 13a: Group VR, time point 01

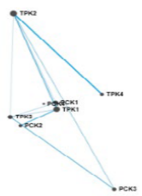

Figure 13b: Group VR, time point 02

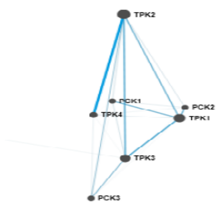

Figure 13c: Group VR, time point 03

Codes	Point of Time	**TPK1**	**TPK2**	**TPK3**	**TPK4**	**PCK1**	**PCK2**	**PCK3**	**PCK4**
VR	**1**	10	10	4	2	4	1	1	0
	2	17	13	14	6	9	5	4	2
	3	26	37	17	15	15	12	9	0
		53	**60**	**35**	**23**	**28**	**18**	**14**	**2**
ZOOM	**1**	8	7	11	1	6	0	1	0
	2	19	18	29	5	9	3	4	1
	3	18	24	28	6	8	6	9	0
		45	**49**	**68**	**12**	**23**	**9**	**14**	**1**

There was nearly no difference in the number of codes regarding the knowledge domains TPK and PCK. Nevertheless, the two groups differed in the distribution and development of the respective connections. The main differences can be seen between the knowledge domains TPK2, TPK3, and TPK4. While the VR group from the start elaborated on the connections between TPK1-TPK2-PCK1 and TP1-TPK3-PCK3, the ZOOM group focused more on TPK1 and TPK2 and TPK3 connections. In point of time 02, both groups' ENA network showed an approximation of both groups to each other, and they seemed to be similar. However, the numbers reported a rise in TPK3 codes for the ZOOM group and PCK2 for the VR group.

b.) GATI Diagrams

Most of the students pictured their development with circles but did not comment or reflect on it explicitly. Only a few students stated how they estimated the difference in overlapping knowledge domains. However, it was noticeable that, instead of using the circle for PK, two participants of the ZOOM group chose PCK as one basic knowledge domain and described its development. Both stated that, since they study in the field of special education, and since PK and CK are always quite closely related to each other, PCK, in their opinion, is a unique body of knowledge.

Figure 14: GATI diagram, Student B, ZOOM, time point 01 and 03

Discussion and Implications

The results summarized above are subject to certain limitations. It is essential to note that a convenience sample was used in this exploratory study. Hence, considering the background of the qualitative research approach and sampling method, the participants are not representative of their respective groups. The results thus may not similarly apply to other pre-service teachers. In addition, the ENA coding process comes with some vulnerabilities, such as subjectivity.

This study aimed to develop a better understanding of how pre-service teachers' TPACK developed over a semester of social VR and ZOOM use. Further, it explored what connections were drawn between the individual knowledge domains that indicated the progress toward a meta-cognitive awareness of how to plan and design a digital media-integrated lesson.

Due to the nature of TPACK, we turned to ENA as a research method and the GATI reflection process, which allowed us to map the emerging connections between the knowledge domains of the respective groups. Particularly, the inclusion of the knowledge levels (Wiesner & Schreiner, 2020) permitted us to analyze the progress students made throughout the lesson design process. Furthermore, the abstraction of the different knowledge domains into factual, conceptual, procedural, and meta-cognitive knowledge offered us the chance to abstract pre-service teachers' learning process. Although this study does not make any claims to holistically display cognitive processes and their nature, from a pedagogical view, the results of mapping pre-service teachers' TPACK allow concluding the implementation of social VR in initial teacher education, the further improvement of the seminar concept and for further TPACK research with ENA.

Overall, the data collected on pre-service teachers demonstrate considerable homogeneity in some instances regarding their development of the basic pedagogical knowledge domains PK1, PK2, PK3, and PK4 and their first transformations. By studying the seminar process and content and the portfolio assessment criteria for passing the course closer, the pedagogical focus becomes apparent and explains the high frequencies of the PK (1–4) connections.

Regarding the quality of the basic knowledge domains, both groups progressed from summarizing and reproducing pedagogical knowledge as factual knowledge to making connections not only to procedural knowledge but also (a few) to meta-cognitive knowledge. However, this homogenous development was only observed regarding the overall consideration. A closer look at the points of time reveals that the VR group established more TK2 (conceptual knowledge) connections in the first period and progressed with PK and CK connections in the second period. Nevertheless, aligned to the seminar concept, after the second point of time it was expected that there would be a similar rise and development of knowledge domains as students of both groups had participated in peer-group supervision and received individual teacher educator's feedback before handing in the portfolio for 02.

The deviations in the development of both groups allow the assumption that the VR group, based on their application experience of VR hard-and software, included the TK2 (conceptual knowledge) components at an earlier stage and, thus, drew connections between PK1-TK2 for their lesson designs more frequently. They rarely used TK1; instead, they drew connections to the conceptual knowledge (TK2). On the contrary, the ZOOM group had no experience using VR in the learning contexts and could assume solely from the seminar's content how its application would influence the planning and designing of lessons. Another aspect that might support this assumption is the development of the content knowledge's progress in the VR group. Although content knowledge was not promoted directly by the seminar concept, both groups made connections to CK. While the VR group developed successively more content knowledge on the conceptual level from the point of time 02 onwards, the ZOOM group participants' frequency of established CK codes decreased from the point of time 02 to 03. According to the situated learning approach, it can be assumed that through the application of VR hardware and software, the participants in the VR group, considering the conceptual implications of integrating VR into their respective school subjects, constructed the knowledge built on their experiences. To do so, they had to delve deeper into the content knowledge to conceptually decide based on their factual knowledge and even more on their experiences about whether their learning objectives could be achieved with VR. The ENA networks showed more complex mental models with more connections between the components than the ZOOM group. This is supported by the second transformation's results, which show more complex TPK4 and PCK3 references made in the VR group. However, the ZOOM group elaborated their portfolios based on their pedagogical knowledge and drew mainly links originating in the pedagogical knowledge domains, leading to more TPK3 references in the second transformation and fewer additional PCK connections. All in all, the results of both groups illustrate a shift toward activating more procedural and meta-cognitive knowledge domains and respective interrelations.

Following the assumption that pre-service teachers in social VR formed more complex mental models in planning and designing VR-integrated lesson plans based on their VR experiences, the importance of integrating VR in seminar concepts in initial teacher education becomes evident. However, whether this development applies across diverse groups should be confirmed by future studies with larger sample sizes. From a pedagogical and empirical point of view the results contribute to a design-based research approach in initial teacher education to derive theory-based design principles for the development of seminars using social VR to promote TPACK of pre-service teachers in initial teacher education.

The findings of this study are currently incorporated into the further development of pedagogical concepts using social VR in teacher education within the ViLeArn project's framework. Moreover, the provision of the pedagogical approaches and the developed materials, as well as the social virtual environment as open source, will contribute to the dissemination of social VR scenarios in different educational contexts.

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6.3 Conclusion

The aim of Study 4 was to evaluate how the refined pedagogical concept can promote pre-service teachers' TPACK as a metaconceptual awareness using social VR. The analysis of the GATI diagrams and the pre-service teachers' epistemic network analysis (ENA) confirmed the successful implementation of the pedagogical concept in practice. The generated design principles led to the development of pre-service teachers' TPACK to successfully implement social VR in class (see Section 6.2). The results of the GATI diagrams demonstrated that pre-service teachers participating in social VR constructed more complex mental models of TPACK than their peers who used Zoom (see Section 6.2). The data from the portfolios revealed that students in the social VR group could anticipate the challenges they would face when using social VR in the classroom (see Section 6.2). Drawing connections between their TK, PK, and CK and the subdomains, they considered more contextual factors when designing their lesson plans. Students also increasingly involved CK in the subject matter, going beyond the knowledge domains fostered by the pedagogical concept (see Section 6.2). One possible implication here is that the pre-service teachers had hands-on experience, whereas those participating in Zoom did not (see Section 6.2).

The development of the pedagogical concept in this work has two implications for the future integration of social VR into ITE. First, the implementation of social VR depends highly on the interplay of pedagogical and technical components and their contextual factors. Through the iterative design and development processes, it was possible to create and implement a pedagogical concept for the promotion of pre-service teachers' TPACK as metaconceptual awareness using social VR that considers important contextual pedagogical and technical aspects.

As VR hardware and software is developing quickly, and the choice of hardware and software influences the nature of teaching and learning activities, the pedagogical concept will need further refinement in the future: A close adaptation of pedagogical and technological design elements is indispensable because these elements are interdependent.

7. Conclusion and Outlook

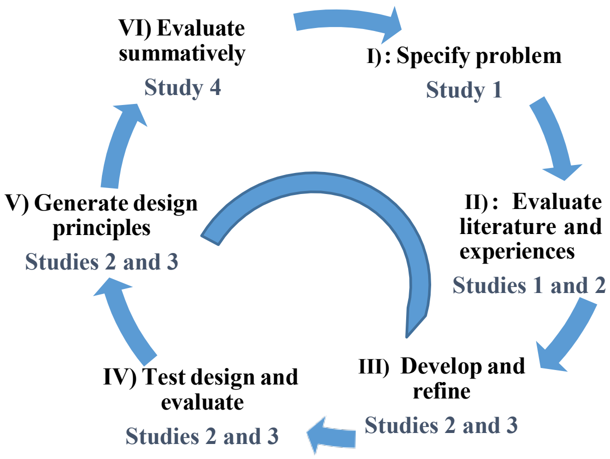
Against the background of the need to provide future teachers with the knowledge to plan and design school lessons using innovative technologies in a practice- and action-oriented way, the aim of this dissertation was to iteratively develop a pedagogical concept that promotes pre-service teachers' TPACK while considering potential social VR affordances. In four studies, the following main research questions were addressed:

- What do student teachers and teacher educators expect of a successful virtual reality application in Initial Teacher Education (ITE?
- How do pre-service teachers perceive teaching and learning activities in social VR?
- How should a pedagogical concept for remote initial teacher education be designed to promote the metacognitive learning processes of pre-service teachers?
- How do pre-service teachers perceive these learning processes in video-based communication and social VR? How did pre-service teachers' TPACK develop using a social VR learning environment prototype compared to a video-conferencing system?

The design and development process of the pedagogical concept to promote pre-service teachers' TPACK as metacognitive awareness in social VR took place through the close interaction of research and practice in a DBR process.

Figure 3

Adaptation of Euler's (2014) DBR structure model



The results of the research process are summarized in this chapter, with the four studies assigned to the phases of Euler's (2014) design cycle (see Figure 3). Furthermore, the limitations of the studies are summarized. Finally, possible consequences and implications are derived for research and teaching practice with special consideration of the two following frames of reference, which are central to this thesis: (a) TPACK as a metaconceptual awareness (Section 2.1) and (b) social VR's affordances for teaching and learning processes (Section 2.2).

7.1 Summary of the Development Cycles and Their Research Results

The design and development processes of the pedagogical concept started by identifying the problem of practice to promote the TPACK of pre-service teachers using social VR. Against the background of a literature review of existing pedagogical and technical requirements (Section 3.2) in Study 1, a needs analysis was carried out to explore what student teachers and teacher educators expect of a successful VR application in ITE. To consider important contextual factors from the perspective of pre-service teachers and teacher educators, 12 pre-service teachers and 10 teacher educators from a German university participated in guideline-based interviews (see Section 3.2). From the results of a content analysis (Mayring, 2015), it was possible to derive key design features of the pedagogical concept to foster pre-service teachers' TPACK in social VR based on existing literature and the in-practice experiences of the target groups (Sections 3.2 and 3.3). Important design features included close guidance and support for using VR hardware and software; accessible and user-friendly materials; elements of constructivist learning theory; and disruption-free communication, collaboration, and interaction in a social VR environment, keeping design elements minor and clean (Section 3.2).

The aim of Study 2 was to analyze how pre-service teachers perceive teaching and learning activities in fully immersive social VR and to derive consequences for further refinement of the pedagogical concept to promote the TPACK of pre-service teachers (Section 4.2). Thus, the results were used to further analyze and explore the design assumptions for teaching and learning processes in social VR. The second study represented the first development and refinement step of the first iterative cycle, which involved the testing and further refinement of design principles (see Euler, 2014). Accordingly, a teacher-centered and learner-centered seminar unit using social VR was designed according to the requirements identified in Study 1. Design principles comprised action-oriented, constructivist, and situated-learning activities and changing social formats.

Further, pedagogical and technical support were integrated. To prevent potential technical obstacles to pre-service teachers' use of social VR hardware and software, the study took place in a lab (see Section 4.2). The seminar unit was implemented with a convenience sample of three groups, each of five students, in the ITE program at a German university. The results of a content analysis (Mayring, 2015) of the three group interviews showed that throughout the seminar units, particularly in the teacher-centered scenario, content representation on virtual boards led to fatigue and decreased concentration among students (Section 4.2). Visual stimuli in the social VR seminar room were kept to a minimum; this strategy was received positively as pre-service teachers felt more present and less distracted than in similar face-to-face settings (Section 4.2). Because of missing verbal and nonverbal abstract avatar representations, students needed more time to carry out their tasks in the group work, substituting missing communications signals with their avatar's body movements or anticipating speakers' turns (Section 4.2). At the same time, positive effects were noted, such as more concentration on the spoken word and being able to state one's mind without fearing criticism (Section 4.2). Target groups mainly imagined possible teaching and learning scenarios in social VR, known from face-to-face teaching and learning scenarios (Section 4.2). In line with the assumption that the feeling of social co-presence positively influences social learning processes and thus benefits collaborative tasks (Garrison & Akyol, 2013) in social VR, students showed excitement, motivation, and engagement throughout the group task (Section 4.2).

The aim of Study 3 was to further refine the pedagogical concept to promote the metacognitive learning processes of pre-service teachers and analyze how such teachers perceive their learning processes in social VR compared with video-based communication. The results of Study 2 were used to adapt the design principles in Study 3 (see Section 5.2). With the key objective of promoting TPACK in social VR, the primary approach of the pedagogical concept not only had to consider social VR's affordances and challenges but also had to enable teaching and learning processes leading to the metaconceptual knowledge of how to implement social VR successfully in class (Section 5.2). Hence, guiding the second iterative cycle (see Figure 3; Euler, 2014) of a pedagogical concept promoting TPACK as metaconceptual awareness in social VR in a remote teaching and learning setting were the following design principles (Section 5.2):

- Active learner engagement with the subject matter.
- Group tasks for small groups.
- Flipped classroom principles and action orientation.

- Clear and structured content representation to prevent students' cognitive overload.
- Use of a potential feeling of togetherness in social VR.
- Close support from a pedagogical and technical perspective.

To address metaconceptual learning processes in particular, a peer group supervision approach was implemented (Tietze, 2010) with joint reflecting, scaffolding, or problem solving as design principles (Section 5.2). The pedagogical concept was implemented with a convenience sample of 17 pre-service teachers at a German university. The students participated in two iterative cycles of peer group supervision, performing design tasks in groups in social VR (n = 12) or using a video-conferencing system (n = 5). Data were collected via guided reflective video statements of students and semi-structured group interviews. Qualitative content analysis (Mayring, 2015) of the group interviews and reflective video statements was deductively carried out according to the four main features of peer group supervision delineated by Tietze (2010): group size, the design task, the structure of peer group supervision, and the communication and interaction processes involved in social VR and Zoom (Section 5.2). The results showed that students perceived the design task as complex and not easy to carry out. Nevertheless, it led to reflective and problem-solving processes, allowing for the consideration of multiple perspectives on and potential solutions to the problem at hand (Section 5.2). At first, the structure of the peer group supervision was hard for the students to follow, but from the second repetition on, they became used to it (Section 5.2). Furthermore, the steps of the peer group supervision process served some students as facilitators of communication processes (Section 5.2). The results emphasized the recurring importance of integrating multiple breaks to relieve cognitive load (see Chandler & Sweller, 1991; Parong & Mayer, 2021; Section 5.2).

Students positively perceived the interaction with peers in social VR and compared it favorably to face-to-face communication and interaction in reality. Notably, this sense of community had significant value for most students because they felt isolated during the pandemic (Section 5.2). Moreover, compared with Study 2 (Section 4.2), the missing social cues represented an advantage because students tried to follow the peer group supervision cycle's structure strictly and used it to initiate and stop speaker turns clearly (Section 5.2). With regard to structuring the teaching and learning process, the study results suggested the importance of enough time being available; this would allow breaks and repetitions to facilitate cognitive and collaboration processes in social VR. It also became apparent that there was still a need for more supportive measures to facilitate social VR's hardware and software use (Section 5.2). Finally, the findings underlined that the right balance between confronting students with pedagogical and technical stimuli and not overwhelming them plays a crucial role in the success of teaching and learning processes in social VR (Section 5.2).

The aim of Study 4 was to evaluate how the refined pedagogical concept can foster pre-service teachers' TPACK as metaconceptual awareness using social VR. After adapting the design principles according to the newly gained insights, the pedagogical concept seemed robust enough to be implemented throughout a semester, covering the full complexity of its future in-practice use for remote teaching and learning processes (Section 6.2). Therefore, investigation was undertaken of how pre-service teachers' TPACK develops when they use a social VR learning environment prototype compared to when they use a video-conferencing system (Section 6.2). The pedagogical concept to foster pre-service teachers' TPACK as a metaconceptual awareness was implemented with a convenience sample of 14 pre-service teachers at a German university.

Following the principles of action-oriented teaching and learning by design (Koehler & Mishra, 2009; Tulodziecki et al., 2017) and peer group supervision (Tietze, 2010), pre-service teachers designed VR-integrated lesson designs in an iterative peer feedback process using social VR (n = 7) or a video-conferencing system (n = 7) and documented their results and further reflections in a portfolio. After each peer group supervision cycle and teacher feedback, the student teachers handed in a new version of their lesson design (Section 6.2).

With regard to data collection, the pre-service teachers' GATI diagrams (Krauskopf et al., 2018) illustrated how they estimated their TPACK before and after the seminar (Section 6.2). The portfolios document the pre-service teachers' design and development process of successfully constructing a lesson plan integrating social VR into the curriculum's framework (Section 6.2). GATI diagrams and portfolio data were coded and qualitatively evaluated with ENA (Shaffer et al., 2016). The results showed that the ENA networks of both groups developed in the PK knowledge domains (Section 6.2). The pedagogical concept and assessment criteria show a pedagogical focus that explains the high frequency of PK-related connections (Section 6.2). The lesson designs of both groups progressed over the semester from the first dimension (factual knowledge) to the third dimension (procedural knowledge; Section 6.2). Few drew connections in the fourth dimension of metacognitive knowledge (Section 6.2).

Overall, both groups developed quite homogenously (Section 6.2). However, a closer look revealed that the lesson designs of the social VR group showed more complex connections involving TK of the second dimension at an earlier stage of the design progress and increased inclusion of CK (see Section 6.2). The results led to the inference that the design principles of the pedagogical concept favored the development of TPACK in social VR (Section 6.2). Based on the overall impression and results, it can be concluded that students who worked with social VR regularly were able to derive implications for planning and designing lessons based on their in-practice experience (Section 6.2).

Experiencing the effort connected to implementing social VR and testing social VR hardware and software, pre-service teachers observed firsthand insecurities, joy, and frustration when using social VR (Section 6.2). Transferring this new understanding to the perspective of their future students, the pre-service teachers gave reasonable justification in their lesson plans for their desire to use a specific VR software for a particular learning objective (Section 6.2). To do so, they had to consider the curriculum of the subject matter and include their CK to weigh the added value of social VR for the individual lesson plan (Section 6.2). Moreover, they were aware of the benefits and challenges of the chosen social VR hardware for school implementation (Section 6.2).

7.2. Limitations of the Studies

The findings presented in this dissertation are subject to certain limitations, as discussed below. Concerning the data, the findings were based on convenience samples of pre-service teachers in Germany. The study sample consisted of student teachers in their first phase of teacher education. Therefore, the findings cannot be transferred directly to pre-service teachers in the second phase of teacher education in Germany or to pre-service teachers in other countries with different models of ITE. In addition, the prerequisites of the participating students varied according to their study progress and focus. Furthermore, a positive sample bias can be assumed because students could choose the course from a variety of other courses covering various topics. Because of the small sample sizes, the results of the exploratory case studies are not representative; however, the precise description of learning prerequisites, targets, teaching, and learning activities, social forms, and digital media allows for a replication or an adaptation of the study for other target groups and aims. Accordingly, the findings of this study provide helpful insights for future research and practice with regard to implementing social VR in ITE and evaluating the promotion of pre-service teachers' TPACK development.

There are also limitations concerning the instruments used to map pre-service teachers' TPACK development in Study 4. Students developed a GATI diagram for the self-reflection process at the beginning and end of the semester in which Study 4 was conducted, showing their TPACK progress over the semester (see Section 6.2). However, the GATI diagram is more of a tool for reflection than a test instrument for measurement. Krauskopf et al. (2018) saw the potential of the GATI procedure as a measurement tool, but to confirm this assumption, more research is needed, including studies with larger sample sizes (see Krauskopf et al., 2018).

The ENA used as the main method to map the development of TPACK comes with some challenges. The coding guide must be highly detailed, and raters must be intensively trained. Because the construction of ENA networks depends significantly on the references made between the codes, coders must set references according to the respective context given by sense units (see Shaffer et al., 2016). To ensure that coders interpret sense units as similarly as possible, several repetitive alignment processes are necessary. While this approach enables the mapping of dynamic cognitive processes, it also carries the risk of open interpretive spaces. To keep such spaces as low in number as possible, in this study, reoccurrences of codes were counted to back up assumptions made about the created mental model networks (Section 6.2).

7.3 Implications and Outlook

As a result of the iterative design and research process, the created pedagogical concept led to the successful promotion of pre-service teachers' metaconceptual awareness of TPACK using social VR. The main underlying concepts of the research questions are as follows: (a) TPACK as metaconceptual awareness and (b) social VR's affordances for teaching and learning processes in ITE. Against the background of these theoretical starting points, the implications for research and practice from the findings of this work are outlined below. The next section identifies fields of action for ITE that require further investigation with regard to fostering TPACK using social VR in ITE.

7.3.1 Modeling Technological Pedagogical Content Knowledge as Metaconceptual Awareness

In the scientific discourse, systematic overviews show the variety of TPACK research studies, but they rarely refer to TPACK as metacognitive awareness (Krauskopf et al., 2012; Krauskopf et al., 2015; Krauskopf et al., 2018). Consideration of metacognitive learning processes could provide beneficial insights into the promotion of the TPACK of pre-service teachers in future research and practice.

This study's findings confirm that pre-service teachers developed TPACK as metaconceptual awareness with the help of metacognitive learning activities in social VR (see Chapter 6.2). TPACK is a framework for teacher knowledge (Mishra & Koehler, 2006); accordingly, further efforts must be made to model and validate the relationship between TPACK and media-related educational competencies. Regarding the goal that pre-service teachers should be able not only to use social VR successfully but also prepare their future students for the self-determined and competent use of social VR (Chapter 1), this requirement implies shifting the main focus of TPACK from the use of educational technology to integrating aspects of media literacy education.

This work focused mainly on the assumed underlying cognitive processes connected to TPACK's development (see Section 6.2). Parong and Mayer (2021) found that emotional arousal based on VR experiences influences learning outcomes and is thus a vital aspect to consider when designing pedagogical concepts for social VR. Accordingly, exploring the affective effects of using social VR on TPACK's development would allow helpful assumptions about how to implement and design social VR software in ITE.

Concerning implications for the in-practice use of social VR to promote TPACK, it would be illuminating to implement student teachers' lesson designs (see Section 6.2) in practice at schools. Using this approach, long-term studies could investigate whether student teachers can transfer their knowledge from theory to practice and apply the metaconceptual strategies acquired in ITE. Based on these findings, further implications for the design, development, and evaluation of pedagogical concepts supporting the promotion of TPACK as metaconceptual awareness could be derived.

7.3.2 Measuring Technological Pedagogical Content Knowledge as Metaconceptual Awareness

Previous research has identified instruments to measure pre-service teachers' TPACK (Section 2.1). TPACK as metaconceptual awareness comprises dynamic metacognitive processes that take place within a two-level transformation process of constructing mental models (first transformation) and TPACK awareness (second transformation) (see Krauskopf et al., 2012; Krauskopf et al., 2015; Krauskopf et al., 2018). This work used the GATI diagram (Krauskopf et al., 2018) and ENA (Shaffer et al., 2016) as two possible tools to map the transformation processes of pre-service teachers' TPACK. Although both instruments proved suitable in Study 4 (see Section 6.2), further research on the topic is necessary. Concerning the GATI process (Krauskopf et al., 2018), in Study 4, student teachers with a study focus on special education indicated that they saw PCK as one of the leading knowledge components and not as a subdomain (see Section 6.2). This perception would have consequences for the interpretation of the mental models and the design of the pedagogical concept. Accordingly, the repetition of the evaluation process with larger groups divided according to study focus and learning prerequisites would allow for more assumptions about the specifications for each TPACK domain. The ENA (Shaffer et al., 2016) provided a way to map TPACK as metaconceptual awareness (see Section 6.2). Since coding and mapping are extensive and require many resources, a possible approach to facilitate the procedure for future in-practice implementations in ITE is to investigate the involvement of AI automation processes.

7.3.3 Teaching and Research with Social Virtual Reality: Implications for Ethics and Sustainability

When using social VR in class, teacher educators and pre-service teachers must decide on appropriate social VR hardware and software for their learners and be aware of possible risks and dangers to which their learners are exposed. Moreover, ethical questions arise with regard to the use of social VR hardware and software because VR's characteristics can affect the user's emotional, mental, or physical state (Chapter 1). Adams et al. (2018) categorized VR's risks into the following: (a) manipulation and violation of immersive experiences, (b) physical harm, and (c) data collection and inferences. Exposing users to a multisensory world in which the stimuli resemble real ones (Gonzalez-Franco & Lanier, 2017) turns VR into a powerful medium.

Harzenmoser et al. (2019), for example, demonstrated that VR could cause psychological trauma and a high level of emotional response, leading to physical suffering. In line with this finding, Slater et al. (2020) listed numerous novel possible harms and risks associated with experiencing “superrealism” (p. 3) created by mixed reality technologies. Accordingly, future research should carefully weigh the expected positive effects and possible risks when using social VR for teaching and learning processes.

Along with social VR’s effects on the state of mind and body of users, data protection is an important issue for further research and practice. The provider retrieves biometrics-related information and the IP address, as well as data about the environment, the location’s dimensions, and users’ motion. Moreover, when using realistic 3D avatars, the question of ownership of such avatars arises. With regard to the rapid further development of technology, these aspects are not only important for future research but also relate to the data literacy of pre-service teachers.

Another dilemma for future research and practice is the sustainable choice of VR hardware and software. Since new VR hardware is developed quickly, IT support may end soon after the headset is bought or the data regulations may change; this may lead to a short period of use and unnecessary e-waste if the hardware soon becomes unusable.

For the future implementation of social VR in ITE, implications for ethics and sustainability are not only important for research but also for TPACK acquisition and curriculum development.

7.3.4 Social Virtual Reality as an Authentic Learning Environment in Initial Teacher Education

As the results of Study 4 showed, using social VR in ITE supports pre-service teachers’ construction of complex mental models (see Section 6.2). Social VR’s affordances offer many possibilities to increase the authenticity of learning environments for ITE (see Wang et al., 2021). The design elements of the social VR platform applied in this work focused on real-world scenarios. Accordingly, seminar rooms and furnishings were based on standard design features from the real world (see Sections 4.2, 5.2, and 6.2). Future development and research on the applied social VR prototype could extend design features to allow a variety of learning scenarios and settings so that pre-service teachers could interact and engage with objects, travel back in time, or teleport to other countries. Furthermore, implementing pedagogical agents in social VR may positively influence teaching and learning processes (see Clarebout et al., 2002, for an overview). Such agents could give immediate feedback cues, comment on the difficulties or benefits of learning activities, point out design elements supporting or hindering learning processes, and act as mentors or peers. Whereas some see pedagogical agents only as a further unnecessary cognitive load for learners (Clark & Choi, 2007), others have proved their potential for positively influencing learning outcomes (Moreno, 2005). In a study conducted during the COVID-19 pandemic, Petersen et al. (2021) found that although the pedagogical agent contributed—as expected-to a higher cognitive load, realistic agents could support the acquisition of conceptual information. Furthermore, they found that realistic agents increase the feeling of social presence (Petersen et al., 2021), which is assumed to influence the co-construction of knowledge and collaborative processes in VR (Garrison & Akyol, 2013). In particular, in such social learning processes as peer group supervision, the use of an agent could either increase the feeling of co-presence or give important feedback to pre-service teachers.

7.3.5 Creating Collaborative Cultures in Social Virtual Reality and Beyond

Previous studies have confirmed the overall positive effect of social relations on teachers' wellbeing, supporting resilience and positive emotions throughout the pandemic (see McCallum, 2021). With the increasing workload and complexity of the teaching profession, mental health and teacher wellbeing have gained in importance (see Hascher & Waber, 2021). Throughout the research and development cycles of this work, positive side effects appeared throughout the collaboration in peer group supervision cycles. Apart from the formal learning setting, students started to form informal study groups outside the university to consult each other regularly on problems, including not only how to organize their study but also pandemic struggles (see Section 6.2). With the help of social media, students coordinated and shared their workloads. It is assumed that peer group supervision contributed not only to the acquisition of metaconceptual strategies for implementing social VR (see Section 6.2) but also to the development of collaboration strategies for coping with workload, the shift to remote studies, and the isolation experienced because of the pandemic. Serving as an informal learning setting outside the seminar framework, peer collaboration was a significant incentive offered by the pedagogical concept (see Section 6.2). Looking forward to possible 21st-century challenges, the curriculum in ITE could contribute to teachers' preparation by offering incentives for the acquisition of coping strategies embracing a collaborative learning culture.

Overall, the present work has demonstrated that in an iterative design and development process, a pedagogical concept was designed that promoted pre-service teachers' TPACK as metaconceptual awareness in a social VR learning environment. TPACK as metaconceptual awareness allows pre-service teachers to acquire metacognitive strategies to successfully plan and design target-oriented social VR-integrated lessons for each grade. As a crucial incentive for learning activities allowing metacognitive processes, such as reflecting, scaffolding, and problem solving, peer group supervision represented an efficient way to combine the benefits of social VR with the pedagogical principles of constructive, situated, and action-oriented teaching and learning. Thus, this work contributes to the current debate in educational policy, educational research, and educational practice concerning pre-service teachers' requirements for the sound and successful implementation of educational technology in their future teaching practice. It is hoped that it will contribute to transforming and opening teaching and learning processes in ITE toward a learner-centered, collaborative, and sustainable learning culture that will help prepare pre-service teachers for future teaching practice and upcoming 21st-century challenge.

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