JUSTUS-LIEBIG-
UNIVERSITÄT
GIESSEN

Communicating in Mixed Reality:
Applications in Digital Participation, Learning and Product Presentation

Tobias C. Stejskal

Doctoral Thesis

2024

Supervisor of Dissertation

Jella Pfeiffer

Prof. Dr.

Co-Supervisor of Dissertation

Axel Schwickert

Prof. Dr.

"These things – they take time."

– Gabe Newell

Table of Contents

Declaration

I hereby declare that I have completed the submitted dissertation independently and only with the help which I have indicated in the dissertation. In the research conducted by me and mentioned in the dissertation I have observed and adhered to the principles of good scientific practice, as laid down in the statutes of the Justus Liebig University Giessen.

Introduction

In the realm of modern technology, several advancements have significantly impacted how we access and share information. Most importantly, the internet has made it possible to retrieve information about virtually any topic. Similarly, smartphones have enabled us to access information on the move, at any time, providing uninterrupted connectivity. However, many digital devices still require specialized knowledge to operate effectively[1]. This can create barriers for individuals who may not have technical expertise, or capabilities[2]. Now Virtual Reality (VR) technology offers a more user-friendly interface[3]. With VR, natural gestures become interactions[4], requiring movement, and spatial awareness rather than technical know-how[5]. This holds the potential to empower more people to engage with digital content effectively. Given VR's potential to overcome existing challenges, it is valuable to assess its suitability for different areas of digital communication.

This dissertation examines the transformative potential of VR across public participation, education, product presentations, and general communication scenarios. Drawing on insights from diverse fields such as urban planning, technology adoption, educational theory, consumer behavior research, and computer-mediated communication, it aims to provide a comprehensive understanding of how VR can advance inclusivity, empowerment, and overall user experiences in the digital realm. By evaluating the above mentioned application contexts, this research highlights VR's capacity to improve digital communication, making it more accessible and effective for users with varying levels of technical expertise. Ultimately, the dissertation addresses the broader question of how VR can be integrated to ensure that digital advancements benefit a diverse population.

[1] Pawel Weichbroth. "Usability of Mobile Applications: A Systematic Literature Study." In: *IEEE Access* 8 (2020), pp. 55563–55577. ISSN: 2169-3536. DOI: 10.1109/access.2020.2981892.

[2] Hasanin Mohammed Salman, Wan Fatimah Wan Ahmad, and Suziah Sulaiman. "Usability Evaluation of the Smartphone User Interface in Supporting Elderly Users From Experts' Perspective." In: *IEEE Access* 6 (2018), pp. 22578–22591. DOI: 10.1109/ACCESS.2018.2827358.

[3] Laura Freina and Michela Ott. "A literature review on immersive virtual reality in education: State of the art and perspectives." In: *The international scientific conference elearning and software for education* 1.133 (2015). DOI: 10.12753/2066-026x-15-020.

[4] Yang LI et al. "Gesture interaction in virtual reality." en. In: *Virtual Reality & Intelligent Hardware* 1.1 (2019), pp. 84–112. ISSN: 2096-5796. DOI: 10.3724/sp.j.2096-5796.2018.0006.

[5] Marcio C. Cabral, Carlos H. Morimoto, and Marcelo K. Zuffo. "On the usability of gesture interfaces in virtual reality environments." In: *Proceedings of the 2005 Latin American conference on Human-computer interaction - CLIHC '05* (New York, New York, USA). New York, New York, USA: ACM Press, 2005. DOI: 10.1145/1111360.1111370.

Different methods are applied in the five publications that are contained in this dissertation, beginning with the development of specialized software that was tailored to the research question using a design science approach. In addition, an empirical survey based on a customized questionnaire was used to systematically collect data from the participants. Publication 4 utilizes sensor data as the basis of a behavioral analysis in order to gain objective insights. Finally, this research includes the conceptualization and refinement of a theoretical model in publication 5. This involves synthesizing existing theories, concepts and empirical findings to develop a comprehensive framework to inform future application and research.

This dissertation consists of five publications, each of which serves as an independent chapter. The first two contributions were created as part of the Take Part project. The goal of Take Part was to evaluate the use of Augmented Reality (AR) and VR in the context of a digital platform for citizen participation. Building on this, the third publication compares the learning of advanced topics between print, 2D content on the computer, and an immersive presentation in VR. In order to then focus on specific user behavior, the fourth publication looks at the interactions of shoppers on the real and virtual supermarket shelves. In the course of this analysis, strong parallels become clear, but it can also be shown that the time intervals differ significantly. Finally, these investigations serve as the basis for the last publication, which introduces an applicable communication model that can be used to compare the suitability of two digital communication systems for any given communication situation.

The emergence of digital government initiatives has enabled improvements to citizen engagement and decision-making processes, marking a significant shift towards more inclusive governance. In the first publication, this serves as a basis to develop and deploy an eParticipation platform. This platform, integrating AR and VR capabilities, empowers citizens to actively participate in the planning and execution of urban construction projects. At the same time, project managers can also guide participation in the respective project by configuring existing modules of this platform, as well as commissioning new content or entirely new modules. This platform not only reduces barriers to participation but also enhances transparency and mitigates conflicts, thereby fostering a culture of digital participation within local government contexts. The focus lies on reducing challenges associated with citizen participation in urban development projects,

which is underlined by the controversy surrounding Stuttgart 21.

The central research question propelling the Take Part project is articulated as follows: "How can citizens be informed about construction projects at an early stage and at a low threshold with the help of AR and VR technologies and can this create an incentive for citizen participation in order to contribute to decisions that avoid later conflicts?" To answer this question, an interdisciplinary consortium, comprising research institutions and companies, collaborated on the development and evaluation of the Take Part app prototype from 2018 to 2021. This publication highlights the evolution of the Take Part app prototype and the accompanying participation ecosystem, detailing how these innovations tackle current challenges in citizen engagement.

Methodologically, the Take Part project employs a multifaceted approach, blending theoretical inquiry, technological innovation, and empirical evaluation. The interdisciplinary nature of the consortium facilitates a comprehensive examination, synthesizing expertise from diverse domains to conceptualize, develop, and appraise the efficacy of the Take Part app prototype. Through iterative design loops and integrating user feedback, the prototype underwent refinement to optimize both usability and effectiveness. By providing citizens with accessible and relevant VR experiences, the project aims to foster collaborative governance, preempt conflicts, and nurture a more inclusive approach to urban development.

During the implementation of the Take Part project, it became clear that the adoption of new technologies poses significant challenges for project initiators. In fact, it required the development of user-friendly solutions and support systems for new projects. In response to these challenges, this publication explores the design and implementation of a configurator – tailored to the Take Part eParticipation platform. By streamlining the integration of AR and VR technologies into the decision making process, project initiators with varying levels of expertise are supported in configuring their projects presence on the platform, thereby simplifying and proliferating access to the benefits of immersive visualizations. The design process of the configurator is described in detail, highlighting considerations such as user experience, customization options, and support for external service providers. The central contribution of the paper lies in the conceptualization, design, and qualitative evaluation of this platform configurator, which enables project initiators to streamline the participation processes, select relevant modules, and interact

with their target audience. It highlights how construction projects can be guided in integrating AR and VR visualization into their citizen communication channels. This configurator therefore facilitates inclusive decision-making processes and empowers citizens to contribute meaningfully to urban development initiatives.

In order to take a closer look at the communication of complex information, the third publication focuses specifically on immersive learning environments. The between-subjects experiment highlights the educational potential of VR, in particular its effectiveness in conveying complex topics compared to more established learning materials. The biological mechanisms of Covid-19 were selected as the learning content, as it was both unfamiliar and interesting to participants at the time. By measuring the short-term and long-term learning outcomes, as well as the subjective self-assessment of the participants, VR can be compared accurately. The study conducts a comparative analysis between VR and standard learning technologies, in particular illustrated text and 2D video on desktop PCs, to assess their relative effectiveness in an educational context. Participants engaged with the learning materials presented in VR, 2D video, or illustrated text formats, with knowledge gain and motivation measured immediately and two weeks after exposure. It identifies VR as a promising tool for immersive learning experiences, based on the ability to simulate complex scenarios and enhance learning outcomes. The results demonstrate that VR has superior short-term knowledge gain compared to traditional methods. While this highlights the value of VR in acquiring new knowledge, it also emphasizes the need to optimize the subjective learning experience within all learning environments. Overall, the study contributes to the understanding of potential applications of VR in education and highlights the need to address the barriers to widespread adoption of VR in educational settings.

The fourth publication explores the potential of VR in the domain of consumer behavior research. Based on a between-subjects study, the shopping behavior in front of a supermarket shelf is analyzed. Participants were either placed in front of real shelf containing muesli, or experienced the identical shelf in VR. While the actions of participants in the front of a real shelf were recorded and transcribed from video, the behavior in VR was recorded in detail. The experimental design seeks to investigate whether shopping behavior observed in VR is comparable to real-world scenarios, addressing questions about the validity of findings obtained in

VR environments. The data consists of 100 participants interacting with virtual and physical product shelves filled with mueslis.

The study analyzes interaction data and product choices. All tasks concluded with actual purchases by participants to enhance external validity. The task setup in the VR store corresponds to a utilitarian fit, indicating specific goal-oriented behavior with low arousal. Analyzing the patterns of product interactions and purchase decisions clarifies consumer behavior across virtual and physical contexts. The study results show that VR users exhibit comparable behavior but are more efficient, contrary to the expected hedonic perspective, which aligns with previous research.

This research primarily contributes to assessing the validity of knowledge gained from VR experiences, especially with respect to physical stores. It directly supports the creation of controlled and easily observable experiment environments, improving factors such as validity and reproducibility. Furthermore, it also identifies challenges and innovations for VR shopping experiences based on observed differences in user behavior, which will inform the design of future VR retail environments.

Finally, the last publication introduces the "Comparing Communication Technology Suitability" (CoCoTeS) model, a framework created by integrating computer-mediated communication (CMC) theories into the VR concept space. Grounded in a synthesis of multiple theories, this model offers a systematic approach to the selection of appropriate communication tools for a given situation to minimize future expenses and enhance processes. The first major contribution of this publication is that it illustrates how concepts from VR research can be used to align multiple CMC theories. While most theories establish their own terminology and dimensions, this approach allows multiple different theories to be applied on a unified basis. But it also introduces the CoCoTeS model as a systematic framework for evaluating communication technologies, incorporating technological, personal and situational aspects. This improves communication technology selection processes, thereby enhancing collaboration, problem-solving, and decision-making outcomes across various contexts.

Ultimately, this dissertation illustrates the transformative potential of VR technology across eGovernance, education, commerce, and communication domains. By highlighting the synergies between technological innovation and effective communication processes, it seeks to chart a course towards a more inclusive, transparent, and equitable future in the digital age.

Ich sehe was, was du auch siehst. Über die Möglichkeiten von Augmented und Virtual Reality für die digitale Beteiligung von Bürger:innen in der Bau- und Stadtplanung

Publisher	HMD Praxis der Wirtschaftsinformatik, Springer
Publication Status	Published 26.08.2021
	https://doi.org/10.1365/s40702-021-00772-6
Author Contribution	0.11 AP
	Software Development, Writing
	Permission to reprint via Creative Commons CC BY license

Facilitating Mixed Reality Public Participation for Modern Construction Projects

Publisher	International Conference on ArtsIT, Interactivity and Game Creation (pp. 275-291), Springer International Publishing
Publication Status	Published 10.02.2022
	https://doi.org/10.1007/978-3-030-95531-1_19
Author Contribution	0.2 AP
	Conceptualization, Methodology, Writing
	Permission to reproduce kindly granted by Springer Nature

Knowledge All Around Me: Comparing the Effect of VR, Text and Desktop on Learning Outcomes

Publisher	*ECIS 2023 Research Papers*, AIS
Publication Status	Published 11.05.2023
	https://aisel.aisnet.org/ecis2023_rp/394
Author Contribution	0.75 AP
	Conceptualization, Methodology, Writing
	Permission to reproduce through the Open Access Policy of the AIS

Let Others Play in your Sandbox: Virtual Reality-based Experiments on Shopping Behavior

Publisher	Working paper; Under review
Author Contribution	0.5 AP
	Data Analysis, Writing

Should I Zoom You After The Metaverse? The Virtual Reality Perspective on Selecting Computer-mediated Communication Technologies

Publisher	Working
Publication Status	Under review since 27.02.2024
Author Contribution	0.8 AP
	Conceptualization, Theory Development, Methodology, Writing

HMD (2021) 58:1180–1195
https://doi.org/10.1365/s40702-021-00772-6

SCHWERPUNKT

Ich sehe was, was du auch siehst. Über die Möglichkeiten von Augmented und Virtual Reality für die digitale Beteiligung von Bürger:innen in der Bau- und Stadtplanung

Jonas Fegert · Jella Pfeiffer · Pauline Reitzer · Tobias Götz · Anuja Hariharan · Nadine Pfeiffer-Leßmann · Patrick Renner · Thies Pfeiffer · Christof Weinhardt

Eingegangen: 3. April 2021 / Angenommen: 20. Juli 2021 / Online publiziert: 26. August 2021

Zusammenfassung Digital Government eröffnet Möglichkeiten, Verwaltungs- und Regierungsprozesse kritisch zu reflektieren und sie entsprechend neu zu denken. Oblagen Bürgerbeteiligungsprozesse in der Vergangenheit zahlreichen Hürden, bietet die e-Partizipation Möglichkeiten, sie mit modernen Technologien zu verbinden, die eine niedrigschwellige Teilhabe ermöglichen. In dem Forschungsprojekt Take Part, gefördert durch das Bundesministerium für Bildung und Forschung, werden innovative Formen der Beteiligung von Bürger:innen in der Stadt- und Bauplanung mithilfe von Augmented und Virtual Reality (AR und VR) erforscht. Dabei geht es vor allem darum, neue Anreize zu schaffen, Bürger:innen zur Beteiligung zu motivieren und durch diese das Konfliktpotential um Bauprojekte zu reduzieren. Mithilfe der innerhalb von Take Part entwickelten App können Bürger:innen Bauvorhaben diskutieren, Feedback geben oder über sie abstimmen, während sie dabei den Beteiligungsgegenstand anschaulich in AR und VR präsentiert bekommen. Zugleich können auch Initiator:innen mithilfe eines Partizipationsökosystems die Beteiligung im jeweiligen Bauvorhaben konfigurieren, indem sie sowohl vorhandene Module kombinieren und konfigurieren, als auch passende Dienstleistungen, wie beispielsweise 3D-Modellierungen, einkaufen. In diesem Beitrag sollen die konkreten technologischen Entwicklungen (u. a. Outdoor-AR-Tracking und räumlich verankerte Diskussionen), sowie das Partizipationsökosystem (Dienstentwicklungs- und Ausführungsplattform) vorgestellt werden. Erstmalig soll so der entwickelte Prototyp umfassend dargestellt werden. Auf die Herausforderung, eine e-Partizipations-App zu entwickeln, die die Möglichkeit bietet, verschiedene Interaktionskonzepte ineinander zu integrieren und gleichzeitig eine überzeugende User-Experience bietet, soll ebenfalls eingegangen werden. Anschließend wird das Potenzial einer solchen Lösung für die digitale Mitbestimmung in lokaler Verwaltung vor allem in Bezug auf gesteigerte Vorstellungskraft und Motivation zur Teilhabe für Nutzer:innen diskutiert und in den Kontext der Covid-19 Pandemie gesetzt.

Ausführliche Informationen zu den Autoren befinden sich auf der letzten Seite dieses Artikels.

Schlüsselwörter Bürgerbeteiligung · E-Partizipation · Augmented Reality · Virtual Reality · Bauplanung · Stadtplanung

On the Potential of Augmented and Virtual Reality for the Digital Participation of Citizens in Construction and Urban Planning

Abstract Digital government opens up opportunities to critically reflect on administrative and government processes and to rethink them accordingly. In the past, citizen participation processes were subject to numerous challenges, but e-participation offers opportunities to combine them with modern technologies that enable low-threshold participation. In the research project Take Part, funded by the German Federal Ministry of Education and Research, innovative forms of citizen participation in urban and construction planning are being researched using augmented and virtual reality (AR and VR). The main goal is to create new incentives to motivate citizens to participate and to reduce the possible conflict in construction projects. With the help of the application developed within Take Part, citizens can discuss construction projects, give feedback or vote on them, and at the same time have the object of participation vividly presented in AR and VR. Furthermore, initiators can configure the participation ecosystem to find combinable applications for participation in the respective construction project and purchase suitable services, such as 3D modeling. This paper will present the concrete technological developments (incl. outdoor AR tracking and spatially anchored discussions), as well as the participation ecosystem (service development and implementation platform). For the first time, the developed prototype will be presented in detail. The challenge of developing an e-participation app that offers the chance to integrate the interaction concepts of different technologies and at the same time provides a compelling user experience will also be described. Finally, the potential of such a solution for digital participation in local government will be discussed, especially in regard of the increased power of imagination and motivation to participate for the user and additionally put into the context of the Covid-19 pandemic.

Keywords Public Participation · E-Participation · Augmented Reality · Virtual Reality · Construction Planning · Urban Planning

1 Einleitung

In Zeiten der Urbanisierung, in der Menschen weltweit vermehrt in Städte ziehen (United Nations et al. 2019), steht die Nutzung öffentlichen Raums im großen Maße zur Debatte. Werden bei Bauprojekten nicht alle beteiligten Stakeholder miteinbezogen, so können Konflikte entstehen, die eine gesellschaftliche Spaltung vorantreiben können. So ist beispielsweise die Belastung der öffentlichen Hand aufgrund steigender Baukosten ein ernstzunehmendes Problem. Die Konsequenzen exklusiver Bauplanung zeigten sich in den vergangenen Jahren weltweit an diversen Konflikten. 2019 kam es in New York City zu der Debatte um eine neue Amazon Firmenzentrale, bei der die Proteste gegen die damit einhergehende Gentrifizierung des

Stadtteils zu einem Abbruch des Bauprojekts führten. In Deutschland war vor allem der Konflikt um die Neugestaltung des Stuttgarter Hauptbahnhofs ausschlaggebend für eine eingehendere Beschäftigung von Bürger:innenbeteiligung und der Frage nach zeitgemäßen Visualisierungen von Bauvorhaben. Stuttgart 21 kann als eines „der umstrittensten Infrastrukturprojekte in Deutschland“ (Brettschneider 2013) beschrieben werden. Die Neugestaltung des Kopfbahnhofs begann 2010 vor allem durch einen Teilabriss des Gebäudes, der zu zahlreichen Protesten führte, der wiederum eine überregionale Öffentlichkeit zusah. Der Konflikt konnte nur durch ein Schlichtungsverfahren und einen Volksentscheid gelöst werden und in der Konsequenz untersuchten Forscher:innen vermehrt, was in Stuttgart genau schief gelaufen war und wie künftig solche Fehler vermieden werden könnten (Schuster 2013). Ein Grund, der wiederholt in der Forschung auftaucht, ist die schlechte Kommunikation (Baupläne waren bspw. nicht an Ort und Stelle für die Bürger:innen einsehbar) der Initiator:innen, die den Bau als alternativlos darstellten (Thaa 2013). Die mangelnde Einbindung von Bürger:innen, sowie eine intransparente Kommunikation der Initiator:innen kann so Vertrauen in Politik und Verwaltung nachhaltig beeinträchtigen. Dieser lokale Konflikt war für die Entwicklung des im Folgenden dargestellten Forschungsprojektes von Bedeutung. Das vom Bundesministerium für Bildung und Forschung geförderte Projekt Take Part folgt der Idee mithilfe zeitgemäßer Visualisierung von Bauvorhaben, die Interaktion zwischen Initiator:innen und Bürger:innen zu verbessern. Mithilfe von Augmented und Virtual Reality (AR und VR) sollen Bürger:innen ermutigt werden, sich an Bau- und Stadtplanung zu beteiligen. AR- und VR-Technologien können durch entsprechende Hardware Räume immersiv erlebbar machen. Im Ergebnis soll so die App Konfliktpotenziale von Bauprojekten frühzeitig erkennen und verhindern. Die Forschungsfrage, die das Projekt begleitet lautet daher:

Wie können Bürger:innen mithilfe von AR- und VR-Technologien frühzeitig und niedrigschwellig über Bauvorhaben informiert werden und kann dadurch ein Anreiz zur Bürgerbeteiligung geschaffen werden, um zu Entscheidungen beizutragen, die spätere Konflikte vermeiden?

Mit dem Ziel dieser Forschungsfrage nachzugehen, fand sich 2018 ein interdisziplinäres Konsortium, bestehend aus Forschungseinrichtungen (FZI Forschungszentrum Informatik, Justus-Liebig-Universität Gießen, Karlsruher Institut für Technologie) und Unternehmen (Raumtänzer GmbH, Neuland Medien GmbH & Co KG und CAS Software AG) zusammen. Dieses arbeitete zwischen 2018 und 2021 an der Entwicklung und Erforschung der App Take Part, die in diesem Artikel als Prototyp erstmals umfassend vorgestellt werden soll. Im ersten Teil des Artikels werden die theoretischen Grundlagen bezüglich E-Partizipation und AR und VR beleuchtet und somit ein Ausgangspunkt für die Beantwortung der Forschungsfrage geschaffen. Das darauffolgende Kapitel führt die beiden Themengebiete zusammen und erarbeitet, welche Chancen AR- und VR-Technologien in Bezug auf Bürger:innenbeteiligung eröffnen. Anschließend werden die Take Part-App (finaler Prototyp) und das Partizipationsökosystem vorgestellt und es wird beschrieben, wie damit den geschilderten Herausforderungen begegnet wird.

2 Theoretische Grundlagen

2.1 E-Partizipation

E-Demokratie beschreibt das weitgefasste Konzept der Nutzung von Informations- und Kommunikationstechnik, um demokratische Beteiligung und Prozesse zu fördern und zu stärken (Macintosh 2004). E-Partizipation kann laut Macintosh (2004) als der Teil der e-Demokratie verstanden werden, durch die die Bürger:innen direkt in die demokratische Entscheidungsfindung eingebunden werden. Sie ist keine Technologie und es geht bei ihr nicht primär um die Nutzung von Technologien innerhalb der politischen Wahlprozesse (e-Voting), sondern vielmehr um eine Form der Bürger:innenbeteiligung die mit ihrem kollaborativen Charakter über das alljährliche Wählen hinausgeht (Sanford und Rose 2007).

Die International Association for Public Participation liefert ein umfassendes Modell zur Kategorisierung von Bürger:innenbeteiligung mithilfe verschiedener Ebenen (International Association for Public Participation 2018). In ihrem Partizipationsspektrum hat jede Ebene der Beteiligung („inform“, „consult“, „involve“, „collaborate“ und „empower“) unterschiedliche Auswirkungen auf die Entscheidungsfindung. Dieses für die klassische Bürger:innebeteiligung angelegte Modell lässt sich auch auf die e-Partizipation übertragen (Nabatchi 2012; Nelimarkka et al. 2014; Wirtz et al. 2018). Die generelle positive Wirkung von Beteiligungsstrukturen auf beispielsweise die Motivation, Leistung und Zufriedenheit von Mitarbeitenden (Wegge et al. 2010) gilt es zu nutzen und auf die Stadtplanung zu überführen. Wolf et al. (2020) gehen auf eben diese Forderung ein und stellen bereits entwickelte Ansätze von Elementen der e-Partizipation für die Stadt- und Bauplanung vor. Als Argumentationsgrundlage für die Notwendigkeit einer intensivierten Forschung in dem Bereich, wird das Beteiligungsparadoxon aufgeführt, welches den Konflikt zwischen einem gesteigerten Interesse an Beteiligung und der zeitgleichen Abnahme von Optionen der Beteiligung für Betroffene im Laufe eines Planungsprozesses beschreibt. Im Kontext der Stadt- und Bauplanung schlägt sich dieser Konflikt darin nieder, dass zu einem frühen Planungszeitpunkt die Beteiligungsbereitschaft der Betroffenen meist niedrig ist, dem liegt aber nicht ein fehlendes Interesse an den Bauprojekten, sondern vielmehr das überfordernde Abstraktionslevel zu Grunde (Wolf et al. 2020). Um dem Beteiligungsparadoxon und seinen Konsequenzen entgegenzuwirken, verweisen die Autoren auf die Chance von e-Partizipation und plädieren dafür die theoretischen Überlegungen mit evidenzbasierten Methoden zu prüfen.

2.2 Augmented und Virtual Reality

In der praktischen Anwendung von AR wird die unmittelbare physische Umgebung mit virtuellen Elementen ergänzt (Azuma 1997). Zudem ermöglicht AR eine Erweiterung der wahrnehmbaren Realität um weitere Informationen wie Textobjekte oder Bilder (Kind et al. 2019). VR lässt hingegen die User:innen in eine interaktive 3D-Umgebung eintauchen (Immersion) und platziert sie:ihn in eine virtuelle Welt (Wexelblat 1995; Suh und Lee 2005). Oftmals wird dies mit Hilfe von Head-Moun-

ted-Displays (HMDs) erreicht, die mithilfe einer Anzeige die virtuelle Umgebung vor das Blickfeld der anwendenden Person setzen (Meißner et al. 2020; Fegert et al. 2020). Suh und Lee (2005) zeigten auf, dass ein VR-Interface Interesse und Wissen zu einem Produkt fördern kann und Peukert et al. (2019) zeigten, dass Immersion zu mehr Spaß bei der Benutzung einer Anwendung führen kann. Auch in der Bau- und Immobilienbranche wird VR eingesetzt, um Interesse an Bauprojekten zu erzeugen (Whyte 2003; Barnes 2016). Wolf et al. (2020) formulieren die Chancen des Einsatzes von AR- und VR-Anwendungen vor allem in den frühen Stadien der Stadt- und Bauplanung. Nach Wolf et al. (2020) könnten AR und VR Technologien als eine Ergänzung von Beteiligungsformaten eingesetzt werden um Verständlichkeit, Nachvollziehbarkeit, Kollaboration und Interaktion von Beteiligten in Planungsprozessen zu fördern. Sie formulieren die Notwendigkeit zukünftiger Forschung bezüglich AR- und VR-Nutzung für konkrete Anwendungsszenarien und den Anforderungen verschiedener Beteiligungsebenen, wozu dieser Artikel und das Projekt Take Part einen ersten Beitrag leistet.

3 Berührungspunkte und Herausforderungen

E-Partizipation bietet Möglichkeiten, Beteiligungsprozesse zu überdenken und technologisch neue Möglichkeiten der Partizipation zu eröffnen. Interessant ist hierbei, welche Funktion konkrete technologische Entwicklungen (u. a. Outdoor-AR-Tracking und räumlich verankerte Diskussionen), sowie das Partizipationsökosystem (Dienstentwicklungs- und Ausführungsplattform) in Prozessen der e-Partizipation einnehmen können, um diese niedrigschwelliger, interessanter und motivierender zu gestalten. Ein Ansatz von Nuernberger et al. (2016) kann beispielsweise aufgegriffen werden, nämlich wie mithilfe von Annotationen kleine Zeichnungen auf mobilen Geräten präzise in 3D auf einem Gebäude platziert werden und zugleich Zeichnungen, Textfelder, Bilder und Audiokommentare innerhalb der Visualisierung hinzugefügt werden können.

Um ein IT-Artefakt zu entwickeln, welches nah an den Bedürfnissen der Anwender:innen gestaltet wird, wurde anfangs auf einen Design-Science-Ansatz von Pfeffers Peffers et al. (2007) zurückgegriffen. Um der steigenden Komplexität gerecht zu werden, wurde dieser während des Forschungsprozesses durch den Ansatz von Kuechler und Vaishnavi (2008) ersetzt. Die Drei-Zyklus-Ansicht für Design-Science-Forschung ermöglicht die Entwicklung des Prototypen transparent und strukturiert zu halten. Um das Problem zu definieren wurde eine qualitative Studie mit beteiligten Stakeholder:innen durchgeführt und später das Artefakt evaluiert (Fegert et al. 2020). Somit folgte die Entwicklung von Take Part einem Ansatz, der die Nutzer:innen ins Zentrum stellte.

Aus Sicht der Bürger:innnen können Technologien wie AR und VR nicht nur eine inklusive und niedrigschwellige Teilhabe fördern, sondern auch die Motivation zur Beteiligung erhöhen und das Vorstellungsvermögen unterstützen (Fegert et al. 2020). Bürger:innenbeteiligung erfordert, dass alle Beteiligten eine ähnliche Vorstellung von den betreffenden Konzepten haben. Gerade in puncto Wissensstand und Expertise ist es jedoch vorhersehbar, dass Wissen der Stakeholder:innen ungleich

verteilt ist und die individuelle Interpretation von präsentierten Konzepten schnell auseinander gehen kann (Rockmann et al. 2015). Wenn dieser Prozess nicht durch klare Kommunikation abgefangen wird, sind Missverständnisse kaum zu vermeiden, welche wiederum einer erfolgreichen Teilhabe im Weg stehen. Studien belegen: Technologien wie AR und VR können diesen Prozess unterstützen, indem sie den Interpretationsspielraum der Beteiligten eingrenzen (Goudarznia et al. 2017). Macintosh nannte bereits 2008 Visualisierungen, darunter 3D-Umgebungen und VR, als eine wichtige Forschungsaktivität der e-Partizipation. Die Idee die Technologien zu nutzen, begann mit der Verwendung der Technologien als partizipatives Element in der Stadt- und Bauplanung (Allen et al. 2011; Rockmann et al. 2015; Goudarznia et al. 2017; Wolf et al. 2020). Auf diese Forschung baut Take Part auf.

Anders als die genannte Forschung (und bereits etablierte e-Partizipationstools) versucht Take Part Beteiligung mithilfe von AR und VR auf allen Ebenen des Partizipationsspektrums („information", „consultation", „involvement", „collaboration" und „empowerment") zu ermöglichen. Um dieses komplexe Unterfangen für die Bürger:innen überschaubar zu gestalten, ist ein Design, dass sich durch Benutzer:innenfreundlichkeit auszeichnet, unabdingbar.

Während das immersive Partizipationsumfeld auf die Nutzung durch die Bürger:innen ausgerichtet ist, soll dabei nicht übersehen werden, dass die **Mitwirkung der Initiator:innen** ebenfalls möglichst umfassend angeboten werden soll. Bauprojekte haben die Eigenschaft, erst dann Aufsehen zu erregen, wenn sie sich bereits in der Umsetzungsphase befinden. In diesem Stadium ist es oft schwer bis unmöglich nachträglich die Bedürfnisse und Anregungen betroffener Bürger:innen miteinzubeziehen und dadurch wird die Chance verpasst Anregungen der Bevölkerung (*Wisdom of the Crowd*) zu bedienen. Kreativer Input und Expert:innenwissen bleibt also in diesem Kontext ungenutzt. AR und VR können dieser Problematik entgegenwirken, indem sie den Bauprozess virtuell in andere Zeitstadien verschieben. Damit kann das sonst zuspätkommende Feedback rechtzeitig eingefangen und Co-Kreation ermöglicht werden (Jutraž und Moine 2016; Imottesjo und Kain 2018). Ebenfalls relevant für Initiator:innen ist, dass Computer-Aided-Design (CAD) bereits von Architekt:innen in der Bauplanung genutzt wird. Daher ist eine technische Grundlage vorhanden, die eine Anpassung für die Nutzung in AR und VR im Kontext von digitaler Beteiligung relativ einfach gestaltet (Lorenz et al. 2016).

Wie bereits das Partizipationsspektrum vermuten lässt, sind die Möglichkeiten Bürger:innen durch (digitale) Beteiligung in die Bauplanung einzubinden vielfältig. Je nach Art des Bauprojektes, seiner geographischen Lage und gesellschaftlichen Stellung, und auch den Interessen der Innitiator:innen unterscheiden sich die Beteiligungsformate in ihren Anforderungen. Die Konfiguration von Systemen der e-Partizipation ist daher wissensintensiv. Sie zu ermöglichen, erfordert aus diesem Grund auch spezifische technische, organisatorische und wirtschaftliche Expertise, die in Abhängigkeit zu dem gewählten Format steht. Initiator:innen stehen somit nicht nur vor der Herausforderung das passende Beteiligungsformat zu dem entsprechenden Projekt zuordnen zu müssen, sondern auch vor dem Problem einer fehlenden Expert:inneninfrastrukur für die technische Umsetzung. Hier soll die Idee eines Partizipationsökosystems Abhilfe leisten.

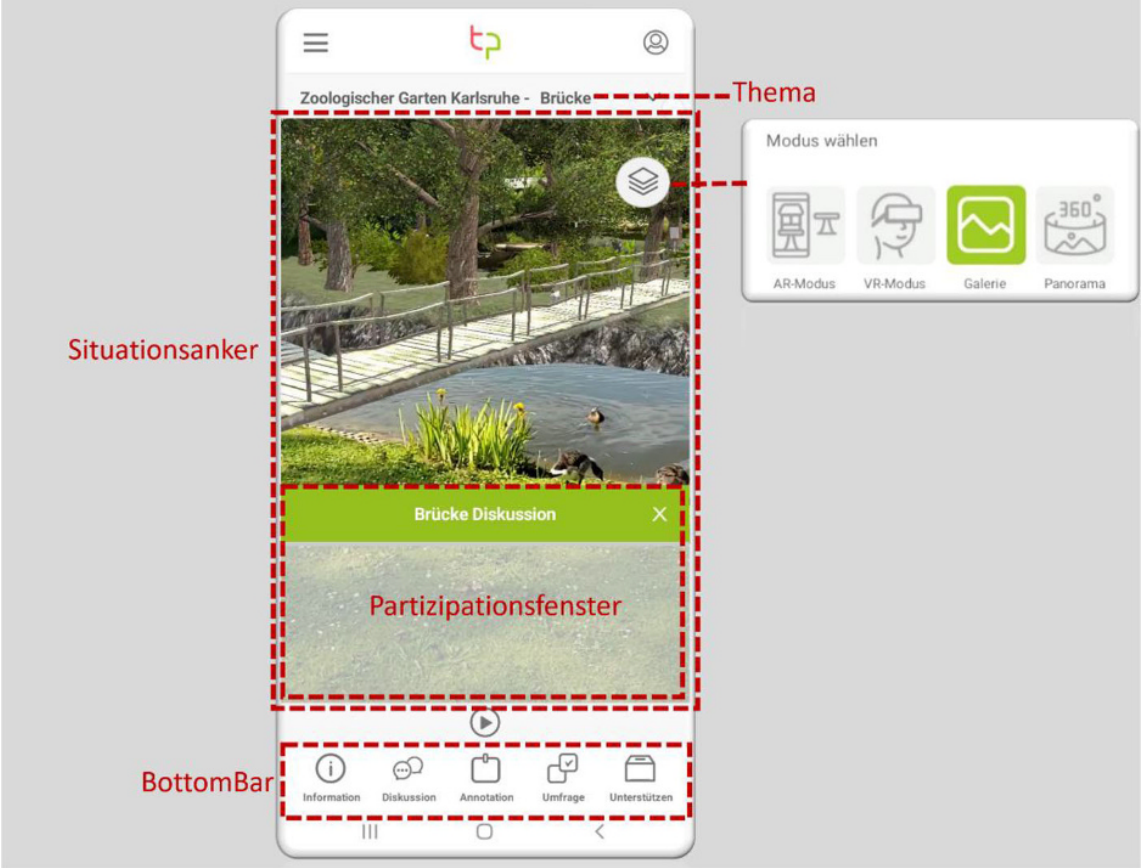

Abb. 1 Der strukturelle Aufbau der Take Part-App

Abb. 2 Die Take Part-App mit seinen AR (**a**) und VR (**b**) Sichtweisen

Abb. 3 Eine Abstimmung zu verschiedenen Versionen einer Außengestaltung

Als Use Case dient im Projekt Take Part der Zoologische Stadtgarten Karlsruhe. Er ist eine Einrichtung der Stadt Karlsruhe, plant jedoch mit Spenden seines Fördervereins, eine Insel in dem parkartigen Zoogelände für die Nutzung als freies Gehege für Kattas, eine Lemuren-Art, umzubauen. Auf die Entwürfe beziehen sich auch die Abb. 1, 2 und 3.

4 Lösungsansätze und ihre Wirksamkeit

Innerhalb des Take Part-Projektes wurde ein Prototyp entwickelt, welcher die oben beschrieben Chancen von AR und VR in der Bürger:innenbeteiligung versucht bestmöglich aufzugreifen. Dieser soll präsentiert werden und gleichzeitig soll auf damit verbundene Herausforderungen eingegangen werden. Die Take Part-App dient dazu, die Initiator:innen und Bürger:innen zusammen zu bringen. Sie bietet eine gemeinsame Plattform zum Austauschen und zum Aufbau eines gemeinsamen Kontexts. Die initiierende Person oder Institution konfiguriert das Projekt und damit die Module in der App so, dass es ihren Wünschen in Bezug auf die Partizipationsmöglichkeiten entspricht. Der Aufbau der Take Part-App spiegelt diesen Ansatz wider und passt sich dynamisch an. Im folgenden Kapitel werden die konkreten technologischen Entwicklungen beschrieben und es wird erarbeitet wie diese den oben genannten Anforderungen gerecht werden.

Initiator:innen gestalten den oberen Bereich der App, indem sie beispielsweise Inhalte des Haupthintergrundfensters als Situationsanker festlegen (Abb. 1). Hier können, um eine gemeinsame Wissensbasis zu schaffen, Bilder hochgeladen, Panorama-Touren verlinkt und AR- oder VR-Modelle eingestellt werden. Die Bürger:innen können in die geplanten Modelle eintauchen und mittels Diskussionen, Annotationen und Umfragen partizipieren. Zudem können die Initiator:innen durch das Vorgeben von Themen dem Projekt eine Struktur verleihen.

Die *BottomBar* der App spannt die verschiedenen Ebenen der Partizipation (s. Abschnitt 2.1) der Bürger:innen auf (Abb. 1). Als ein Ansatz eines nutzer:innenzentrierten Designs wurden zudem Situationsanker entwickelt, die Partizipationsmodule wie Information, Diskussion, Annotation, Umfrage und Unterstützen in der immersiven Umgebung verankern. Das angewählte Partizipationsmodul legt sich als transparentes Fenster (siehe Partizipationsfenster in Abb. 1) über den Hintergrundkontext, sodass die Bürger:innen im gewünschten Situationsanker interagieren können. Die Grundsatz-Designanforderungen der Take Part-App folgen dabei den Maximen: Orientierung schaffen, Situiertheit, Vertrautheit, Multiperspektive (alle Informationen und Konzepte direkt im parallelen, einfachen Zugriff), Aktualität (Information über Neuigkeiten seit letztem Aufruf), Rechteverwaltung (zielgruppenspezifische Zugriffe) und klare Trennung zwischen Informationen von Initiatoren und Bürger:innen. Durch die Umsetzung dieser Anforderungen wird vor allem die Nutzer:innenfreundlichkeit für Bürger:innen sowie Initiator:innen sichergestellt.

4.1 Umsetzung der immersiven Beteiligung

Eine besondere Herausforderung bei baulichen Planungsvorhaben besteht in dem Übergang von 2D-Plänen zu einer 3D-Einordnung von Situationen aus einer personenbezogenen Perspektive. Um dies zu ermöglichen, bietet die Take Part-App AR- und VR-Visualisierungen. Stehen Bürger:innen vor einer geplanten Baufläche, so können sie sich durch Scannen eines Markers, beispielsweise eines Schilds, mittels AR direkt das geplante Objekt in der Realwelt anzeigen lassen. Somit kann die Person genau die Maße und das Einpassen des Bauobjekts in die Umgebung abschätzen. Abb. 2 (links) zeigt das reale Schild zum Scannen, ein virtuelles Informationsschild und ein virtuelles Modell der geplanten Brücke. Für nicht zugängliche Bereiche auf der Insel können User:innen in das VR-Modell wechseln und sich damit direkt auf die Insel in das Modell *teleportieren*. In der VR kann der/die Bürger:in sich bewegen und überall umschauen. Informationsschilder bieten themenbezogene Informationen und dienen als Partizipationsorte (Abb. 2 links). Die App liefert dem:der Nutzer:in ein Partizipationserlebnis, welches Informationen nicht nur realistisch vorstellbar macht, sondern durch Interaktivität auch zu Kreativität und Beteiligung motivieren kann.

Oft besteht bei Diskussionen das Problem, dass die Beteiligten nicht den gleichen Wissensstand beziehungsweise die gleichen Vorstellungen haben. Diskussionen in einem Forum finden zudem zumeist asynchron statt, was diese Problematik noch verschärft. Daher bietet die Take Part-App das Konzept der Situationsanker, um Beiträge in einem Kontext zu verankern. Wenn sich Bürger:innen beispielsweise ein neues Modell eines Katta-Schlafhauses ansehen und äußern möchten, dass die

Kattas zu wenig Rückzugsmöglichkeiten hätten, so können sie den Kommentaren eine Verankerung mitgeben, an welcher Stelle des Geheges ihnen dieser Gedanke kam. Andere Bürger:innen können den Link, in Abb. 2 (rechts) repräsentiert durch den Pin, abrufen und werden so direkt in den Kontext der Äußerung versetzt. Durch die dezente Verlinkung des Situationsankers wird der Diskussionsfluss nicht gestört, die Nachvollziehbarkeit von Äußerungen jedoch erhöht. Die Take Part-App integriert *Rocket.Chat* als Tool für Diskussionen, ergänzt dieses jedoch durch JavaScript-Erweiterungen, um diese spezifischen Zusatzfunktionalitäten zu ermöglichen.

Möchten Bürger:innen unabhängig von einer Diskussion eine Anmerkung machen, so können sie Annotationen (z. B. Audiokommentare sowie ergänzende Bilder oder Kommentare) direkt an einem Ort in der AR-/VR-Welt verankern. Eine weitere Funktionalität, die die Take Part-App unterstützt, ist die Varianten-Visualisierung. Die Initiator:innen können Konfigurator-Schilder aufstellen, die für Bürger:innen die Bauvorhaben direkt visuell erfahrbar machen, ohne einen komplizierten Transfer aus technischen Zeichnungen leisten zu müssen. Basierend auf der Variantendarstellung kann der Initiator auch zu einer Umfrage überleiten, um ein Meinungsbild einzuholen oder eine Abstimmung vorzunehmen. Die Bürger:innen können die Varianten kommentieren oder up-down voten, sowie auch eigene Vorschläge mit konkreten Bildbeispielen anheften und so auch Alternativen vorschlagen. Die Situationsanker konkretisieren somit die Beiträge der Bürger:innen indem sie sie den infrage stehenden Objekten (z. B. dem Schlafhaus der Kattas) zuordnen können. Somit liefern sie eine Wissensgrundlage und wirken dem Wissensvorsprung zwischen Initiator:innen und Bürger:innen entgegen. Missverständnisse über Baupläne können durch diese Funktion vorgebeugt werden.

Aufgrund der unterschiedlichen Technologien besteht eine Herausforderung bei der Umsetzung von AR- und VR-Inhalten in mobilen Apps darin, gleichzeitig eine optimale User Experience bei der App-Nutzung sowie eine optimale Performance und Qualität der immersiven Darstellungen sicherzustellen. Die Take Part-App löst dieses Problem, indem es zwei technologische Ansätze kombiniert. Die grundlegende App wurde nativ mit dem *Xamarin*-Framework umgesetzt. So kann eine stimmige User Experience garantiert werden. Die immersiven Inhalte wiederum wurden mit der *Unity*-Spiel-Engine entwickelt. Diese erlaubt flexible und performante Umsetzung von 3D-Anwendungen, auch für AR und VR: Das ARFoundation Framework vereint die nativen AR-Bibliotheken *ARCore* (Android) und *ARKit* (iOS) und stellt ein stabiles Tracking sicher. Die in *Unity* erstellten Inhalte werden als Plugin in der *Xamarin*-basierten App geladen und komplett integriert.

4.2 Umsetzung des Partizipationsökosystems

Die Initiator:innen bekommen in der Take Part-App mithilfe eines sogenannten Partizipationsökosystems, das man sich wie einen digitalen Marktplatz vorstellen kann, die Möglichkeit ein Partizipationsumfeld zu konfigurieren. Das Partizipationsökosystem bringt Technologieanbieter:innen, Branchen-Softwarespezialist:innen und Content-Betreiber:innen zusammen und ermöglicht es Initiator:innen Partnerschaften zu gestalten und notwendige Expertise nach projektspezifischem Bedarf zu integrieren. Durch wiederverwendbare Technologiebausteine können innovati-

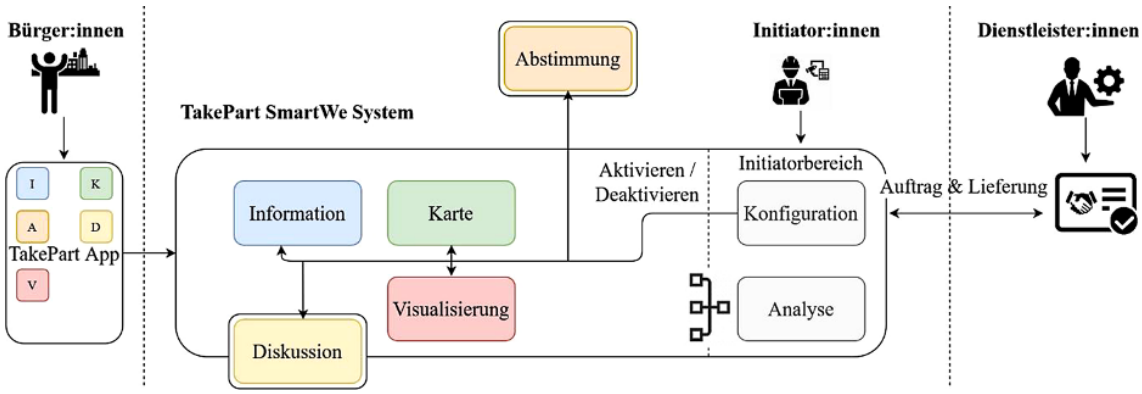

Abb. 4 Das Take Part-Partizipationsökosystem

ve Lösungen für unterschiedliche Zielbranchen entwickelt und eingesetzt werden. Dieses Partizipationsökosystem ermöglicht aus Perspektive der Initiator:innen einen Austausch mit den Bürger:innen zu initialisieren, flexibel zu konfigurieren, zu führen und laufend auszuwerten. Neben dem kreativen Input der Bürger:innen, der sich so für Initiator:innen erschließen lässt, ermöglicht das Partizipationsökosystem eine vereinfachte technische Umsetzung der Beteiligungsformate (z. B. durch die Überführung von CAD-Modellen von Architekten in die AR/VR-Umgebung). Des Weiteren können hier Expert:innen, beispielsweise zur Erstellung von 3D-Modellen, beauftragt und hinzugezogen werden, um bei der Umsetzung des Partizipationsverfahrens zu unterstützen. Durch die Bereitstellung dieser Infrastruktur kann somit auf verschiedenste Anforderungen von Beteiligungsformaten reagiert werden.

Um die Anforderungen in Bezug auf Anpassbarkeit, Erweiterbarkeit und Flexibilität, die durch die facettenreichen Projekte der Initiator:innen erforderlich sind, umzusetzen, wurde auf ein modulares Systemkonzept gesetzt. Das Take Part-Partizipationsökosystem, basierend auf der *SmartWe* Software der CAS Software AG, stellt einzelne funktionale Komponenten (sogenannte Module) bereit (Abb. 4: Information, Karte, Visualisierung). Zusätzlich lassen sich auch externe Dienste (Abb. 4: Abstimmung unter Verwendung von *LamaPoll*), sowie interne, unabhängige Dienste (Abb. 4: Diskussionsmodul, basierend auf *Rocket.Chat*) als Module einbinden.

Initiator:innen beginnen die Erstellung ihrer Projekte mit einem Konfigurationsdialog, der ausgehend von den gewünschten Partizipationsebenen eine Modulkombination empfiehlt. Nach der Auswahl der gewünschten Zusammenstellung (Abb. 5) werden die benötigten Kompetenzen für die Inhalte und den Betrieb aller Module vorgestellt. Die Initiator:innen haben ab diesem Zeitpunkt die Möglichkeit benötigte Inhalte oder Verwaltungsaufgaben selbst zu übernehmen oder sie über das Take Part-System an externe Dienstleister zu vergeben. Kommt es zur Vergabe an externe Service Anbieter, so werden Beauftragung, Lieferung und Integration vom Take Part-Partizipationsökosystems übernommen. Die Suche erfolgt basierend auf dem Ort und der hinterlegten Kompetenzen. Über den *SmartWe*-Appstore kann der Initiator die App auch mit vorhandenen CRM-Apps skalieren – beispielsweise mit Projektplanungswerkzeugen oder Besucher:innenberichten. Die gesamten Konfigurationsschritte für die Projektpräsenz können von Initiator:innen jederzeit erneut aufgerufen werden, um strukturelle Änderungen vorzunehmen.

Abb. 5 Darstellung Initiator System (Auswahl von Modulen, Projektdatenverwaltung, Modul Vorschau, und Beteiligung Dashboard)

Die Daten aus der Verwendung der Module werden den Initiator:innen in beschränktem Umfang als Datenaggregation in einem Dashboard zur Verfügung gestellt. Damit lässt sich anschließend nicht nur die sinnvolle Konfiguration der Projektpräsenz validieren, sondern zusätzlich können durch Umfrageergebnisse und offene Diskussionsbeiträge auch wichtige Einsichten zum Projekt erzielt werden. Für Initiator:innen stellt die Take Part-App somit einen übersichtlichen, homogenen Einstieg in das Partizipationsökosystem dar. Es besteht zusätzlich keine Notwendigkeit bei einem internen Modul- und Kontextwechsel die Nutzer:innen zu authentifizieren und ermöglicht somit eine schnelle, ungehinderte Interaktion mit den Inhalten.

5 Fazit

Ziel des Take Part-Projektes ist die Erforschung von Methoden, um Bürger:innen mithilfe von AR- und VR-Technologien frühzeitig und niedrigschwellig in Beteiligungsformate zu Bauvorhaben einzubinden. Als Lösungsansatz zu der Forschungsfrage stellt dieser Artikel zwei technologische Entwicklungen vor; die Take Part-App und das Partizipationsökosystem. Im Speziellen geht dieser Artikel darauf ein, welche konkreten Anforderungen sich aus einer Nutzung von AR- und VR-Technologien in der Bürger:innenbeteiligung ergeben und wie der entwickelte Prototyp darauf zu reagieren versucht. Eine vorherige Analyse der Möglichkeiten und Herausforderungen ist unbedingt notwendig, um die Entwicklung und das Design des Prototypen danach auszurichten.

Dieser Artikel legt dar, wie die Take Part-App mit AR- und VR-Visualisierungen und Features wie beispielsweise dem Situationsanker eine immersive Beteiligung schafft. In weiteren Studien, die aus dem Forschungsprojekt hervorgingen (Fegert et al. 2020), konnte zudem bestätigt werden, dass die Visualisierung von Bauprojekten mithilfe von AR und VR in unserer App die Nutzer:innen zur Partizipation motiviert und ihre Vorstellungsvermögen unterstützt. Den Visualisierungen gelingt es, eine ähnliche Wissensbasis für die Beteiligten zu schaffen – getreu dem Motto *ich sehe was, was du auch siehst*. Interessanterweise gingen die Take Part Visualisierungen über die bloße Veranschaulichung hinaus, indem sie Nutzer:innen das Gefühl geben konnten virtuell aus der Umgebung der Studie an den Projektstandort versetzt zu werden (Fegert et al. 2020), was als Gefühl der Telepräsenz bezeichnet wird. So können die oftmals trockenen Partizipationsprozesse um Bauvorhaben eine spielerische Dimension erreichen, die niedrigschwellig zu Beteiligung anreizt.

Durch die Integration von hochwertigen AR- und VR-Visualisierungen in ein erprobtes Grundgerüst konnte des Weiteren eine flexible, aber auch verlässliche Basis für das Take Part-Partizipationsökosystem erzielt werden. Die erprobten Konfigurationsmöglichkeiten ermöglichen eine Reihe von Chancen, die bisher Bürger:innen und Initiatoren:innen nicht so unmittelbar zur Verfügung standen. Beteiligungsformate können somit beispielsweise ohne aufwendige technische Expertise an die verschiedenen Anforderungen der Projekte angepasst werden. Diese Konfiguration der Plattform ermöglicht die Erarbeitung eines Bauvorhabens als kollaboratives Produkt und bietet damit bisher nicht vorhandene Zugänglichkeit für Bürger:innen und Initator:innen.

Technisch besteht weiterhin die Notwendigkeit einen Kompromisses zwischen ausreichender Identifizierung der beteiligten Bürger:innen und digitaler Selbstbestimmung zu erreichen. Die Umsetzung der AR- und VR-Funktionen als native, lokale Erweiterung der Take Part-App erwies sich als notwendig, da die erforderlichen Webstandards für diese neuartigen Technologien noch nicht die bestehenden Anforderungen erfüllen.

Die Covid-19 Pandemie hat wie unter einem Brennglas Probleme und Herausforderungen von Gesellschaften aufgezeigt. Die Digitalisierung von öffentlicher Infrastruktur ermöglichte es Staaten schnell auf die Pandemie zu reagieren und gleichzeitig mit ihren Bürger:innen zu interagieren. Hier sehen wir für eine App wie Take Part große Möglichkeiten Partizipation und zwischenmenschliche Einigungsprozesse zu ermöglichen, die komplexes Wissen einfach übersetzen. Mit der innovativen Form der Visualisierung, die wie im Fall von AR lediglich ein Smartphone bedarf, wird eine solide Wissensbasis geschaffen. Daher sehen wir in der vermehrten Nachfrage nach e-Partizipation in Krisenzeiten (United Nations 2020) eine Chance für unseren Lösungsansatz.

Abschließend muss selbstkritisch beleuchtet werden, dass das Take Part-Partizipationsökosystem zwar für private Bauprojekte geeignet scheint, jedoch der regulatorische Rahmen für öffentliche Bauvorhaben Bürger:innepartizipation erschwert. Das deutsche Baurecht sieht bisher keine digitalen Partizipationsmöglichkeiten vor, gerade wenn es um die konkrete Ausgestaltung von Bauvorhaben geht. Die handelnden Akteur:innen möchten sich zudem oftmals, dies ist auch eine Lehre aus unserem Forschungsprojekt, ihre Kompetenzen nicht streitig machen lassen. Daher

konnten wir zwar aufzeigen, dass die digitalen Lösungsmöglichkeiten verfügbar und einsetzbar sind, jedoch wenn es um die konkrete Umsetzung geht, der Wille der Initiator:innen entscheidend ist. Die Etablierung von Technologien wie AR und VR im Massenmarkt wird jedoch auch den Druck auf öffentliche Träger erhöhen, sie innovativ einzusetzen. Denn es liegt nahe, dass Bürger:innen Technologien, die sie im privaten zunehmend nachfragen und schätzen, auch für die Mitgestaltung ihres Umfelds, dem öffentlichen Raum, nutzen wollen. Hierfür haben wir einen Lösungsansatz aufgezeigt.

Funding Open Access funding enabled and organized by Projekt DEAL.

Literatur

Allen M, Regenbrecht H, Abbott M (2011) Smart-phone augmented reality for public participation in urban planning. In: Proceedings of the 23rd Australian Computer-Human Interaction Conference. ACM, New York, S 11–20

Azuma RT (1997) A survey of augmented reality. Presence Teleoper Virtual Environ 6:355–385. https://doi.org/10.1162/pres.1997.6.4.355

Barnes S (2016) Understanding virtual reality in marketing: nature, implications and potential. Social Science Research Network, Rochester

Brettschneider F (2013) Großprojekte zwischen Protest und Akzeptanz: Legitimation durch Kommunikation. In: Brettschneider F, Schuster W (Hrsg) Stuttgart 21: Ein Großprojekt zwischen Protest und Akzeptanz. Springer, Wiesbaden, S 319–328

Fegert J, Pfeiffer J, Peukert C, Golubyeva A, Weinhardt C (2020) Combining e-participation with augmented and virtual reality: insights from a design science research project. ICIS 2020 proceedings. https://aisel.aisnet.org/icis2020/digitization_in_cities/digitization_in_cities/4 (Erstellt: 14. Dez. 2020; Zugegriffen: 14. Dez. 2020)

Goudarznia T, Pietsch M, Krug R (2017) Testing the effectiveness of augmented reality in the public participation process: a case study in the city of Bernburg. Wichmann, Berlin

Imottesjo H, Kain JH (2018) The Urban CoBuilder—A mobile augmented reality tool for crowd-sourced simulation of emergent urban development patterns: Requirements, prototyping and assessment. Comput Environ Urban Syst 7:120–130

International Association for Public Participation (2018) IAP2 Spectrum of Public Participation. www.iap2.org/resource/resmgr/pillars/Spectrum_8.5x11_Print.pdf

Jutraž A, Moine JL (2016) Breaking out: new freedoms in urban (re) design work by adding immersive environments. Int J Archit Comput 14:103–118

Kind S, Ferdinand J-P, Jetzke T et al (2019) Virtual und augmented reality. Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag, Berlin

Kuechler B, Vaishnavi V (2008) On theory development in design science research: anatomy of a research project. Eur J Inf Syst 17:489–504. https://doi.org/10.1057/ejis.2008.40

Lorenz M, Spranger M, Riedel T et al (2016) CAD to VR—A methodology for the automated conversion of kinematic CAD models to virtual reality. Proc CIRP. https://doi.org/10.1016/j.procir.2015.12.115
Macintosh A (2004) Characterizing E-Participation in Policy-Making. In: 47th Hawaii International Conference on System Sciences, Big Island, Hawaii. https://doi.org/10.1109/HICSS.2004.1265300
Meißner M, Pfeiffer J, Peukert C, Dietrich H, Pfeiffer T (2020) How virtual reality affects consumer choice. J Bus Res 117:219–231
Nabatchi T (2012) Putting the "Public" Back in Public Values Research: Designing Participation to Identify and Respond to Values. Public Administration Review 72(5):699–708. https://doi.org/10.1111/j.1540-6210.2012.02544.x
Nelimarkka M, Nonnecke B, Krishnan S et al (2014) Comparing Three Online Civic Engagement Platforms using the Spectrum of Public Participation. UC Berkeley: Center for Information Technology Research in the Interest of Society (CITRIS). Zugegriffen: 04. Aug. 2021
Nuernberger B, Lien K-C, Grinta L et al (2016) Multi-view gesture annotations in image-based 3D reconstructed scenes. In: Proceedings of the 22Nd ACM conference on virtual reality software and technology. ACM, New York, S 129–138
Peffers K, Tuunanen T, Rothenberger M, Chatterjee S (2007) A design science research methodology for information systems research. J Manag Inf Syst 24(3):45–77
Peukert C, Pfeiffer J, Meissner M, Pfeiffer T, Weinhardt C (2019) Acceptance of Imagined Versus Experienced Virtual Reality Shopping Environments: Insights From Two Experiments. In: Proceedings of the 27th European Conference on Information Systems (ECIS), Stockholm & Uppsala, Sweden, June 8–14, 2019. https://aisel.aisnet.org/ecis2019_rp/153 Zugegriffen: 04. Aug. 2021
Rockmann L, Raabe S, Adler S (2015) Augmented-Reality als Erweiterungs-Tool des partizipativen Austausches in Planungsprozessen zum Ziel einer integrativen städtebaulichen Entwicklung. Real Corp 2015 Plan Together—Right Now—Overall From Vision to Reality for Vibrant Cities and Regions Proceedings of 20th International Conference on Urban Planning, Regional Development and Information Society, S 83–92
Sanford C, Rose J (2007) Characterizing eParticipation. International Journal of Information Management 27(6):406–421. https://doi.org/10.1016/j.ijinfomgt.2007.08.002
Schuster W (2013) Politikgestaltung als lernender Prozess: „Stuttgart 21" aus einer politischen Sicht. In: Brettschneider F, Schuster W (Hrsg) Stuttgart 21: Ein Großprojekt zwischen Protest und Akzeptanz. Springer, Wiesbaden, S 329–343
Suh K-S, Lee YE (2005) The effects of virtual reality on consumer learning: an empirical investigation. MISQ 29:673–697. https://doi.org/10.2307/25148705
Thaa W (2013) „Stuttgart 21" – Krise oder Repolitisierung der repräsentativen Demokratie? PVS 54:1–20
United Nations (2020) Embracing digital government during the pandemic and beyond. Economic Analysis & Policy Division,
United Nations, Department of Economic and Social Affairs, Population Division (2019) World urbanization prospects: the 2018 revision
Wegge J, Jeppesen HJ, Weber WG et al (2010) Promoting work motivation in organizations: should employee involvement in organizational leadership become a new tool in the organizational psychologist's kit? J Pers Psychol 9:154–171. https://doi.org/10.1027/1866-5888/a000025
Wexelblat A (1995) Virtual reality: applications and explorations. Academic Press,
Whyte J (2003) Innovation and users: virtual reality in the construction sector. Constr Manag Econ 21:565–572. https://doi.org/10.1080/0144619032000113690
Wirtz BW, Daiser P, Binkowska B (2018) Integrated Model of E-Participation. In: Farazmand A (Hrsg) Global Encyclopedia of Public Administration, Public Policy, and Governance. Springer, Cham. https://doi.org/10.1007/978-3-319-31816-5_3143-1
Wolf M, Söbke H, Wehking F (2020) Mixed reality media-enabled public participation in urban planning. In: Jung T, tom Dieck MC, Rauschnabel PA (Hrsg) Augmented reality and virtual reality: changing realities in a dynamic world. Springer, Cham, S 125–138

Affiliations

Jonas Fegert (✉) · Pauline Reitzer

Information Management & Analytics, FZI Forschungszentrum Informatik, Berlin, Deutschland

E-Mail: fegert@fzi.de

Pauline Reitzer

E-Mail: reitzer@fzi.de

Jella Pfeiffer

Professur für Digitalisierung, E-Business und Operations Management, Justus-Liebig-Universität Gießen, Gießen, Deutschland

E-Mail: jella.pfeiffer@wirtschaft.uni-giessen.de

Tobias Götz

Lehrstuhl für Digitalisierung, E-Business und Operations Management, Justus-Liebig-Universität Gießen, Gießen, Deutschland

E-Mail: tobias.goetz@wirtschaft.uni-giessen.de

Anuja Hariharan

CAS Software AG, Karlsruhe, Deutschland

E-Mail: anuja.hariharan@cas.de

Nadine Pfeiffer-Leßmann

Neuland Medien GmbH & Co KG, Rheda-Wiedenbrück, Deutschland

E-Mail: pfeiffer-lessmann@neuland-medien.de

Patrick Renner · Thies Pfeiffer

Raumtänzer GmbH, Rheda-Wiedenbrück, Deutschland

Patrick Renner

E-Mail: patrick.renner@raumtaenzer.com

Thies Pfeiffer

E-Mail: thies.pfeiffer@raumtaenzer.com

Christof Weinhardt

Institute of Information Systems and Marketing, Karlsruher Institut für Technologie, Karlsruhe, Deutschland

E-Mail: christof.weinhardt@kit.edu

Facilitating Mixed Reality Public Participation for Modern Construction Projects: Guiding Project Planners with a Configurator

Lena T. Schramm[1(✉)], Anuja Hariharan[1], Tobias Götz[2], Jonas Fegert[3], and Andreas P. Schmidt[4]

[1] CAS Software AG, 76131 Karlsruhe, Germany
{lena.schramm,anuja.hariharan}@cas.de
[2] Justus-Liebig-Universität Gießen, 35390 Gießen, Germany
tobias.goetz@wirtschaft.uni-giessen.de
[3] FZI Research Center for Information Technology, 76131 Karlsruhe, Germany
fegert@fzi.de
[4] Karlsruhe University of Applied Sciences, 76133 Karlsruhe, Germany
andreas_peter.schmidt@h-ka.de

Abstract. Digital public participation formats are an emerging and accessible way to involve diverse groups of citizens in construction projects in their local area. Particularly, mixed reality can help project initiators to visualize the planned changes to the city landscape in an easy and understandable way, enabling people to participate in a creative manner. However, this technology is challenging for most project initiators, as it requires an extensive technical and/or domain experience. Besides that, specialized hardware and experienced staff is required. An easy on-boarding process, which introduces mixed reality step-by-step and offers assistance by external service providers could promote both adoption and usage. In this paper, we present the design process and resulting concept of a configurator for a public participation platform, that aims to guide initiators with different levels of technical knowledge. Besides detailing the design and development process of the prototype, we will present the preliminary results of our evaluation. The interview partners provided positive feedback on the usage of our configurator. Moreover, different approaches are necessary for the public and private sector when configuring and purchasing their participation solution. Finally, we highlight areas that are still in need of further work, such as the compliance with the regulations for public institutions and address further promising areas of research.

Keywords: Public participation · Mixed reality · Construction projects · Product configuration

1 Introduction

Eliciting citizen's participation in public projects has remained a challenge. Although construction projects and urban planning directly affect everyday life of many individuals, it is difficult to motivate people to engage with the projects more in-depth [1].

M. Wölfel et al. (Eds.): ArtsIT 2021, LNICST 422, pp. 275–291, 2022.
https://doi.org/10.1007/978-3-030-95531-1_19

Visualizing ideas using augmented reality and virtual reality seems to be a promising approach to arouse interest and provide information, as well as to foster participation in the form of ideas and discussion about a project [2, 3]. City planners and project initiators are often faced with the complex task of delivering different types of information to distinct audiences [4] that need to be made available. Participation requirements may vary across projects, initiated by the same client. For instance, the extent and kind of information to be provided, and whether citizens ought to be involved in a consulting role or rather as a customer might differ. Participation is seen today as a spectrum [5] of different activities that ranges from informing to empowering citizens by placing decisions in their hands. Although several approaches have been highlighted for modular and configurable e-participation architectures [6, 7], there is a dearth of examples that are suited for construction projects employing visualization techniques such as mixed reality (MR). In addition, although several of these platforms can be customized for different projects, there are few examples that function as a configurator as well as a market place for services and providers in case of insufficient competencies by the initiating institutions. In this paper, we present the concept, design and development of a platform configurator. Project initiators can configure their participation process, customize it by choosing relevant participation modules and features. In addition, they can use the platform to interact with as well as offer interaction opportunities to their target population.

Since MR is still regarded as an emerging technology, the willingness to utilize it is an important factor in our research. The current adoption of MR and more specifically virtual reality (VR) devices is still low, as can be illustrated with the Steam Hardware Survey[1]. According to the reported owner numbers among users of this digital video game store, one of the key target groups of this technology, currently ~2,3% own such a device. This is significantly higher than the adoption in the general US population[2,3], where virtual reality still struggles to gain traction [8]. Accordingly, it must be assumed that less technology-savvy users do not yet have any experience with MR systems, therefore it needs to be introduced to them and its benefits must be demonstrated.

Additional to a flexible configuration, project initiators can be supported with external service providers during the configuration process and find support for competencies (such as mixed reality content) that are not readily available. The prototype is developed as part of the research project Take Part[4]. The design process is described in detail, followed by the presentation of the prototype, and an overview of the evaluation by means of qualitative interviews. First results show the need to adopt different on-boarding processes for private and public sector construction projects.

[1] https://store.steampowered.com/hwsurvey (last accessed 2021/06/30).

[2] https://www.emarketer.com/content/us-virtual-augmented-reality-users-2021 (last accessed 2021/10/07).

[3] https://omdia.tech.informa.com/pr/2020-dec/six-and-a-half-million-consumer-vr-headsets-will-be-sold-in-2020 (last accessed 2021/10/07).

[4] https://takepart-projekt.de/take-part/ (last accessed 2021/10/18).

2 E-Participation and the State of Configurators

E-Participation emerged in the 2000s as an interdisciplinary research area in between computer science, information systems, political science and public policy [9, 10]. Our early exploration of the topic took place in the field of various small-scale experiments, local governments and small startups conducted with the involvement of citizens through basic tools, which were often developed only for a specific use case [11]. With the general shift towards a platform economy, the development of e-participation artifacts also shifted towards more elaborate concepts, which were no single purpose tools but suitable to be easily rolled out and modularized by non-experts. The European platforms CitizenLab[5], Adhocracy+[6]and Dialogzentrale[7] are well-known examples based on the described business model and marketed accordingly. These platform services were then adopted by cities like Berlin, Utrecht, Seattle and London. The content is maintained by employees of the respective city and the software is either operated by the cities or the platform providers themselves. In addition, although several marketplace examples exist for shared cloud computing providers, there is a dearth of configurable platforms that are tied to an appstore and a marketplace-like concept for different types of service and content providers [12, 13]. The technological options, therefore, heavily depend on the platform providers and an extension of the existing modules with new functions is not intended.

With the research project Take Part, we would like to propose an e-participation platform that offers more flexibility for the initiators of public participation processes through its configurability. Therefore, we are suggesting the use of a configurator with integrated marketplace for e-participation, where initiators can both select participation modules as well as commission third parties with technical and domain expertise. In our case studies, we examined this marketplace model with particular attention to the integration of MR in e-participation. The basic assumption was that the technical capabilities of these initiators would neither allow the creation of high-quality 3D models, nor the creation of separate MR applications. To allow them to keep up with major shifts in the technological market, like the mainstream use of augmented reality (AR) on smartphones, we propose a collaborative marketplace [14] where external service providers can be hired by the respective initiator itself. Subsequently, those external providers can then create content in the specified format, which is then seamlessly integrated in the existing e-participation ecosystem. Depending on the digital maturity of the project initiator, if 3D models in required formats are available from the design phase, these can be directly uploaded on the system and be prepared for consumption in virtual or augmented reality. In case new models have to be created, suitable service providers can be suggested by the system, which the project initiator can choose from and collaborate with, to create their design alternatives for public participation.

We see an advantage in shrinking the existing interdependence between the cities and the individual companies, by arguing that project initiators could then more easily start a participation process with a small selection of modules and later move on to more

[5] https://www.citizenlab.co/de (last accessed 2021/06/30).
[6] https://adhocracy.plus/ (last accessed 2021/06/30).
[7] https://www.zebralog.de/node/275 (last accessed 2021/06/30).

complex forms of participation (like MR visualizations). Thereby, they would not be committed from the beginning on towards a specific kind of participation process and could respond in a more agile way to the citizens' wishes. A collaborative marketplace could therefore simplify the implementation of e-participation. This flexible and simple on-boarding process could be attractive for project initiators, that first want to get to know the platform and get comfortable with all the possibilities offered. Furthermore, due to the enormous price differences that can arise from the use of MR visualizations, comparing different agencies and configurations at the time of purchase can help local government agencies to be more cost efficient. The design and development process of the configurator with a collaborative marketplace for e-participation will be detailed in the following section.

3 Design Guidelines for the Platform Configurator

In order to develop a configurator for the participation platform Take Part, an analysis of successful, existing configurators was carried out. Patterns applicable to the configuration problem at hand were identified. For this purpose, the technique reverse wireframing [15] was applied. In reverse wireframing, a system, such as a website or an app, is reduced to its elementary structures and elements and all aesthetic designs, images, and content is omitted. Analysis of the desired design is hence possible without visual noise and distractions, since the focus is only on the structure of the system and its elements. With the technique, also used in re-engineering of existing systems and structure, considerable time can be saved in the development of a new system. The tool "Balsamiq" was used to create the wireframes (see Fig. 1).

3.1 Usability Guidelines

To achieve the goal of guided configuration, the configurator should have a good usability [16, 17] and therefore be intuitive and easy to use. To this goal, we derived a number of principles from existing configurators, the criteria laid out by the "Konfigurator-Verzeichnis"[8] and considered similar existing research [18]. The following central design principles resulted from analysis as well as the evaluation of the wireframes:

Navigation. First, the user should be aware at any time in which step of the process they are situated in, what has already been configured, which options are still available and which attributes of the product are being changed at the moment. The various configuration options should be clearly grouped and, if necessary, divided into steps.

Support. Second, to improve support and guidance during the configuration process, descriptive texts in the form of tooltips or info pop-ups can be utilized to guide and support the user. In each step of the configuration, an info button is available. An info pop-up can be opened, to see a description of the current step. However, reading these texts should not be a prerequisite for easy and correct use of the system. The system should assist the user in observing restrictions. These should either be considered automatically; matching

[8] https://www.konfigurator-verzeichnis.de/ (last accessed 2021/06/30).

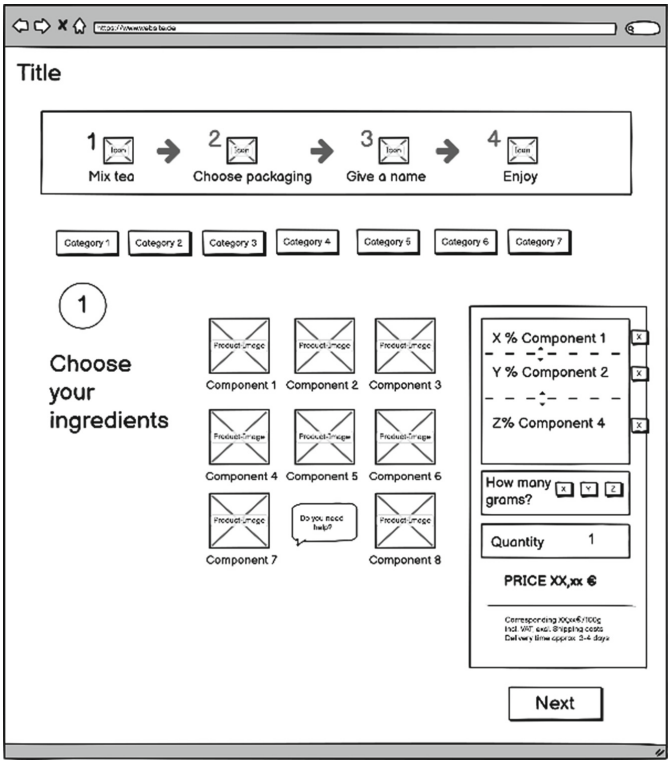

Fig. 1. Mockups using reverse wireframing for the pilot study.

components should only be shown so the user can choose, or a warning message should emerge showing an incompatibility.

Look & Feel. Third, to promote usability, intuitive operating concepts such as drag-and-drop functionalities can be used when appropriate. Another commonly used concept is card design [19–21], where the focus is on the product image and a headline. Further, important information such as the current total price of the configuration, the individual components and important technical characteristics should always be available. In the best case, there should be a list or an information sheet on which the information about the current configuration is displayed.

Short Loading Times. Fourth, short loading and waiting times can have a positive impact on the user experience (UX) in addition to usability. To achieve a short waiting time, data transfer should be efficient. In the configurator, this can be achieved by loading only new page content and keeping the rest of the layout constant. This concept is implemented, for example, in a one-page design, in Progressive Web Apps [22], or a single page application [23].

3.2 Design Dimensions

Decision Support Systems are already extensively researched and sophisticated models exist to represent the use of these systems [24–28]. These, however, are beyond the scope of this research and a simplified model was created instead. This model was based, in addition to the usability findings from the evaluation, on the following design dimensions.

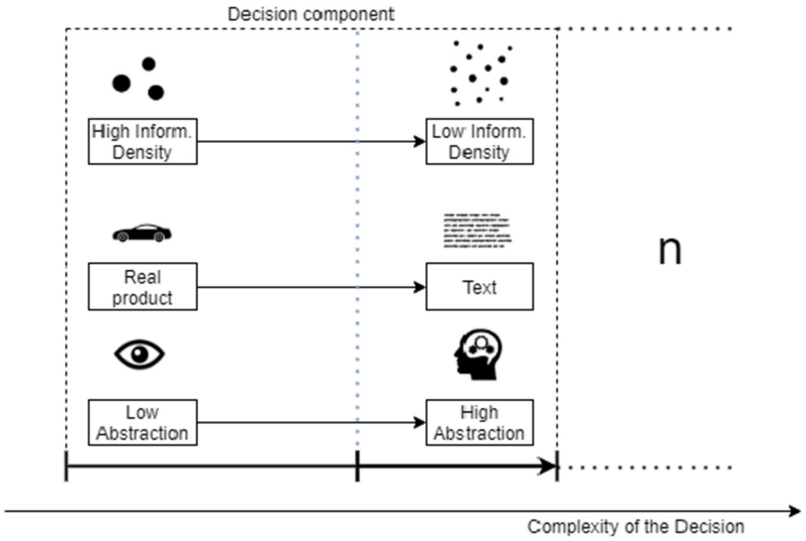

Fig. 2. Design dimensions for user decision complexity.

As illustrated by Fig. 2, a decision consists of one or more decision components that influence it. For example, choosing a set of modules contains multiple decisions about the need of specific single modules. The complexity of a single component is determined by the following dimensions which we applied in our design process.

Information Density: Low - High. The first dimension concerns the presentation of information. It can be decided that the user of the configurator should be provided with as much information as possible on a topic. The more information is offered, the better is the awareness for the topic. However, with more information, cognitive fatigue increases, as the user has to repeatedly decide whether the provided information is relevant to him or not. Hockey refers to this process as "management of control" [29], the decision to do the right thing, which is a major cause of cognitive fatigue. Therefore, the amount of information must be appropriately balanced. In the configuration process, there should always be enough information about a component, an element, a decision step, and the product. However, the user must not be inundated with too much text, whereas product photos are helpful, as they can be easily understood. The analysis revealed that many configurators interact with information tools to provide customers with access to further information if required. This enables non-expert users with a greater need for information to use the configurator better, whereas experts can ignore this functionality.

Product Representation: Textual Description - Real (End) Product.
Another dimension lies in the product representation. The product can be presented to the user in detail. The most accurate presentation is the actual product. For example, in the presentation of a "virtual reality" module, the product can be visualized and presented to the user with VR glasses. This presentation is both time and cost intensive, since technical aids may be required, a demonstration must be possible, or the product might not even be fully developed before a customer places an order. The other extreme is a preview image or textual description of the module. A balance must be found between insufficient product description and marketing cost. The closer the representation is to the real product, the higher the associated cost. For some modules, a demonstration does

not require much effort because it is an available or easily represented software product. This dimension is expected to correlate inversely with information density and abstraction, as an accurate demonstration is more dense in comparison to a highly abstract description of the product.

Decision-making Process: Simple (Binary) - Complex (Non-binary). The problem of making the right decision can be facilitated or encouraged by the complexity of the decision process. The user could be required to make only binary decisions at each step. For example, when selecting suitable components, they could be presented one choice at a time and the user only has to decide whether they are needed or not (yes/no). This, however, lengthens the configuration process by a considerable margin. If several decisions are made in a step, the process shortens but the user has also a higher cognitive load. In summary, the higher the number of decisions in one step and the higher the complexity of each decision, the more complex is the overall decision process. However, in the individualization of a product, the user should also be given the feeling of having a wide range of choices. The number of available options per component should not be too low, but also not too high, as the user could quickly feel overwhelmed [30], whereas a low number may be insufficient for experts. When presented with many configuration options, the user should be supported in the decision-making process by a filter function or automatic preselection. In Fig. 2 this is represented by the number of decision components that are part of a decision.

The dimensions presented were taken into account in the development of designs and the selection of suitable patterns.

4 Platform Configurator Development

After analyzing existing configurators, a process for configuring the Take Part participation platform was developed. The designs and ideas developed were evaluated in a pilot study to determine the most appropriate approaches. The results of the analysis were used to design the process with suitable UI elements and to develop drafts for a prototype. In this section, the different steps and UI decisions made for the configurator that resulted out of the pilot study are described. For the evaluation we chose a combination of a quantitative and qualitative approach. Based on a questionnaire we created polarity profiles and determined the preferred designs. For this we used the "user experience questionnaire" (UEQ[9], short version) and a slightly adapted version of the "system usability scale" (SUS) [31]. Additional to the questionnaire we conducted one-on-one interviews and applied the thinking aloud method [32]. With a few exceptions, the participants were employees of a leading mid-sized software firm and experts in the field of UX and interface design. A detailed summary of the procedure and the results have been published [33]. In the following steps, "user" refers to the project initiator and/or the project coordinator handling the construction process as well as the publicity, marketing and participation experts in charge of the processes.

[9] https://www.ueq-online.org/ (last accessed 2021/06/30).

4.1 Concept

The following steps were derived for the configuration process. At the beginning of the configuration, the user is taken to a start page where the participation platform Take Part and the app are briefly described. A video can be found in which the platform is concisely explained and demonstrated.

Step 1: General Information about the Project. At the beginning of the configuration, the user defines general information about the project needed to advise the user later in the configuration process. This includes, for example, the purpose they are pursuing by providing the participation platform, as well as the geographical range of people they wish to reach. In order to be able to create a basic version of the project page on the platform or to facilitate subsequent consultation, information such as the name of the contact person, the project name, the location of the construction side and the planned project duration, already existing website or brief description are gathered. This information can be used, for example, to determine which citizen groups are notified about the new project on the platform. The range is determined by specifying a radius around the location of the construction project on a map, which is compared to the location of registered citizens. Other definitions of outreach could include specifying a particular city, country, or even targeting a user group, such as a company's employees. If necessary, it must be specified here whether the project is publicly available or should only be visible to a specific audience.

Step 2: Goal of Participation. In the second step, the goal of public participation can be defined using the mentioned Participation Spectrum [5]. It consists of five successive stages in which the citizen's influence on decisions increases progressively, accompanied by promises to citizens, which are communicated implicitly or explicitly. The user selects the desired participation level. These are briefly described and are used to recommend modules in Step 3, *module selection.* In the next step ("module selection"), to give a complete overview, all non-recommended modules are nevertheless present and displayed to the user regardless of their choice.

Step 3: Module Selection. In the module selection step, the project initiator can select the required participation formats that will be available for participating in the project. These are described briefly in the overview to be comparable at a glance, but more detailed information is available as well. A video can be provided for each module, to support the users' understanding. In addition to the attribute-level constraints, there are some inter-module dependencies to consider from a business perspective. For example, the "Surveys" module is only relevant if citizens have previously been informed by the "Information" module or an MR element about the topic on which they are to vote on. However, it is possible that a project initiator may still wish to purchase only one of the modules. The module options should therefore be available and only a recommendation should be given by the configurator.

The modules are thus divided into two lists: recommended modules and other modules. An overview of the modules in the basic package is also provided (Appendix Fig. A). The modules can be filtered by price, interaction options and participation level. Each module is assigned to a participation level. All modules whose assigned level is

less than or equal to the level previously selected by the user are displayed as "Recommended". In addition, the user should have the opportunity to get a preview about the available modules and what is offered even before the configuration. This can be provided on a regular website external to the configuration process. Finally, an analysis of the previous configuration indicates the extent of various aspects (information for citizens, feedback collection, interactivity, opportunities for participation). These aspects have to be explored and improved in future research.

Step 4: Additional Functionalities. Once matching modules have been selected, their functionality can be configured. Additional features for each module, such as displaying a video or photo gallery, are presented to the users and they can decide which of them are needed and which remain deactivated.

Step 5: Marketplace for External Service Providers. For a participation process and most modules, certain specific competencies may be required, which the project initiator can fulfill on his own or which an external company can provide in the form of services. For example, the project initiator may already have received a 3D model from an architect and does not need any support in this regard. However, if this is not the case, they must find a provider/a specialized company who can create the required 3D models - compatible for augmented and virtual reality displays. The configurator thus shows the user which skills, content, or even technical equipment they need for the selected modules. The users can then decide whether they provide these themselves or obtain them from a provider.

In the configurator, providers can be suggested from which the project initiator can obtain an offer, or a service can be booked directly during the process (Appendix Fig. B). For this purpose, a partnership can be entered into with providers, or the "Competence Atlas" product from CAS Software AG can be linked via an interface. Similar to the project "farmshops.eu - direct marketer map"[10] of the Open Knowledge Foundation Germany, providers with certain competences can be found via a map. A special focus can thereby lie on local providers, with promotions to support them. The Competence Atlas hence functions as a marketplace, for users to find providers with specific domain expertise or technical competencies in a specific domain.

All available service providers and partner companies are displayed in a list, in case the user needs support. The name of the company and its distance from the project location are displayed. In addition, a short advertising text is available, as well as a link for references, through which the user can further inform himself about the provider. In addition, the location of the providers can be viewed on a map.

Step 6: Summary. The last step of the configuration process is a summary of the selected components (modules, additional functions, service providers) and the purchase. In order to offer the project initiators more flexibility and assurance, the user can send a non-binding appointment request for a consultation. An analysis similar to that during the configuration process is shown at the end of the configuration, which illustrates the selected modules and summarizes the expected participation effect. The various modules (apps) are bundled as a software package and made available through

[10] https://farmshops.eu/ (last accessed 2021/06/30).

the platform. Authorizing other users to assist in managing the project site and publishing content should be possible by default. In addition, a dashboard should be available for project initiators to view a summary of participation results.

There are several approaches to designing the configurator and the individual steps in the configuration process. Mockups were created for each step and the process flow as a whole. Since there are no technical dependencies between the individual modules and the definition of the exact contents is not considered within the scope of this research, a configuration in the direction of a "pick-to-order" configurator is possible. However, since the modules have to be configured with respect to the activated additional functions and added providers, the complexity of the configuration problem is more like an "assemble-to-order" problem. There are simple dependencies that have to be taken into account and the functions are available as prefabricated modules. The entire configuration process can be iterated several times by the user by adding new modules and new content in an agile fashion.

5 Prototype and Evaluation

5.1 Programming the Prototype

The designed configuration process is implemented as a web application in the CRM cloud solution SmartWe[11] [34]. The configurator should enable project initiators to create a new project in the Take Part app for making it available to citizens (horizontal scalability). The project data and activated modules and additional functions are transmitted to SmartWe via a REST API[12] as a JSON object. In the prototype, the Java library "smartdesign" is used to access the Web API of SmartWe. The Take Part app retrieves all the data records located in the database. The newly created project can thus be seen directly in the app, and further content can be added and maintained. After configuring a project, if the construction initiator wishes to book additional modules, the configuration process shown can be run through again.

Each page and some of the UI elements, such as the shopping cart or analysis are organized as components. Communication between the components is carried out with the help of a service. The "Module", "Additional function" and "External provider" features are products that can be purchased by the user during configuration. Additional functions and modules contain a list of jobs: for example, the "Live chat" function which can be activated in the "Discussion" module might require a moderator. The resulting job of moderating the chat can be done by the project initiator himself, or by an external service provider. Each job contains a list of service providers that can be considered for the task, considering inputs such as latitude and longitude, and range (in km) of service providers. Results are aggregated from external databases of third-party providers in Germany and depicted as hotspots and routes on the Yellow map[13] solution. After a project has been successfully created on the platform, the project initiator can manage

[11] https://smartwe.de/ (last accessed 2021/06/30).
[12] https://partnerportal.cas.de/SmartDesignSDK/SmartWe/ (last accessed 2021/06/30).
[13] https://www.yellowmap.com/ (last accessed 2021/06/30).

the content on the platform environment. In further development, the project should only be made public at the request of the project initiator after the content of the project has been completed.

5.2 Evaluation

To evaluate the prototype, the target group – project initiators – were identified and interviewed to assess feedback and potential improvements to the app. To this end, twelve semi-structured qualitative interviews were conducted with experts from different construction project contexts to evaluate the platform. Methodically, we followed a research approach suggested by Kaiser [35]. The interviews began with an introduction into the Take Part app and MR technologies to make the interviewees acquainted with MR. This was followed by concrete questions on specific topics concerning the initial and long-term usage of the app (such as desired participation levels by the initiator, use of configurator, relevant modules, interest in MR, and so on). Although, in this chapter preliminary results of those interviews, based on notes created from these interviews are presented, a detailed analysis based on a full transcription of the interviews could give more insights. For the complete analysis of the study, the interviews will be transcribed and a structured content analysis based on Kaiser [35] performed, using the software MAXQDA. In this paper, we present the qualitative interviews' preliminary results.

The interviews recognized, that the developed configuration process is well accepted by project initiators from the private sector and is suitable for this purpose. The participants rated the prototype as easy to use, well-structured and user-friendly. Further, they evaluated the configuration of the platform as intuitive and all steps were comprehensible. The interview partners stated that a filter option in the list of available service providers would be important to them in the provider selection process. In addition, detailed offers for the required services were reported to be missing. With a detailed service description, which was not available in the prototype, the interviewees reported that they would publish their project on the platform via this channel. However, all initiators insisted on a consultation appointment before making a final purchase decision, in which the contractual framework conditions and modules of the platform would be explained in greater detail. They would only waive this condition if a comparatively low investment value was required. Large companies that want to use the platform in the long term prefer an individual purchase agreement. It is therefore recommended that different price models be made available for SMEs and large companies, and that individual offers will be made possible.

The situation is different for project initiators from the public sector. In this case, cities that want to use the platform for their own projects are bound by the public procurement law that applies in Germany, particularly when commissioning service providers to fulfill its public tasks(Bundesgesetzblatt[14]). Therefore, project initiators from this area cannot select and commission any external service provider as designed but must publish a call for tenders for the required service. The same regulations apply to the platform itself. Take Part's offer therefore must be compared with similar participation platforms before a city can use the platform, unless they are below a certain cost limit. In future

[14] https://www.gesetze-im-internet.de/vgv_2016/ (last accessed 2021/06/30).

development, it must be examined to what extent the public sector can be supported in the tendering of required services.

Regarding the importance and acceptance of MR technologies in public participation processes by project initiators, at least four out of the twelve interviewed initiators found it essential to provide a good "media mix" to citizens, and perceived the introduction of MR elements in public participation processes as an "interesting" element. One initiator reported that for long term usage of public participation, more intelligent interaction methods for users would be necessary, and mixed reality is a promising approach in this regard. More than 50% of the initiators were not convinced of the necessity of MR for a digital participation process, of which two interviewees reported this being potentially owing to ow low levels of experiences with MR technologies. Initiators expressed concerns on acceptance owing to the ability of MR to reach the masses, particularly reaching citizens who are not mobile or techno-affine. The availability of accurate 3D models, achieving a high quality of MR experiences, and maintenance of 3D data in the planning process, were also perceived as hurdles in long-term usage of MR. In summary, the mixed reality aspect was not reported to be the key deciding factor that determined the use of the platform[15]. However, one initiator reported, that he/she believed sufficient marketing and an appealing, suitable presentation of MR content, would pave the way to increase acceptance of MR for public participation processes. Given that citizens had a very positive reaction to the use of MR for visualizing public construction processes, as shown from pilot studies and in final evaluations [36, 37] of the prototype, the move towards MR technologies for public participation could be driven by the increasing acceptance and usage amongst citizens.

6 Next Steps and Outlook

In this paper we developed design guidelines and a simplified dimensional model for designing and developing a platform configurator for public participation. Although the model was only tested specifically in our use case, we achieved good results in the prototype in terms of usability and acceptance. Even if there are additional dimensions to be considered, in our case it was sufficient to only focus on the three main dimensions summarized. In a more detailed analysis the interrelationship between the components and the decision complexity should be investigated further.

[15] Most of the initiators assumed, that they would use first the simpler, more familiar modules (such as providing surveys, information, photos, etc.) and found the networking effect of the platform useful (the ability to find service providers through the marketplace, as well as to connect with citizen pools of projects made publicly available by other initiators).

From the preliminary analysis of the interviews, we developed several insights for the future development of the configurator. The legal framework for citizen participation is major design driver for such platforms. There is considerable difference between the approaches for the public and private sector, both in terms of procurement processes as well as legal requirements for citizen participation. This applies to both using the platform services as well as the marketplace functions. Project initiators from the public sector have more restrictions during the configuration of the platform than those from the private sector. In the future, especially project initiators of the public sector should be able to specify a service description in the configurator, which is then automatically put out to tender. Suppliers can then send bids to the city management. The configuration process and the platform must be checked for conformity with regulations on participation processes applicable in Germany and the EU.

Furthermore, during the development and evaluation of the configurator it was recognized that the use of the levels of participation is not optimally suited. Rather than using a simple linear model for describing participation along several stages, it has become more promising to use a pattern-based approach in which configurations are chosen "by example" and based on successful configurations, which are selected based on similarity. Moreover, in the configuration process, it is important to ensure that the project initiator has thought about the intended participation process in detail in advance in order to avoid unconsidered selection of modules. Hence, a more generic approach of selecting modules based on categories or templates is recommended for specific use cases.

Support and recommendations for the project initiators can be further improved by using data on participation processes that have already taken place. For instance, a knowledge catalog on already completed reference projects can be provided. With this, project initiators can find out about similar projects that used the platform in the participation process and understand which modules were used at what stage of participation in the project. The result of the participation and the acceptance of the modules by the citizens involved can also be described there. A presentation of selected reference projects can also increase trust in the platform. Further, guidance during the process can be improved by providing recommendations for the use of certain modules and functionalities. In future work the effects of modules and functionalities on a participation process and citizens need to be analyzed. After that, an analysis of the participation platform based on the users' configuration and recommendations supported by artificial intelligence, can be implemented. In the later development of the participation platform, the required data to derive recommendations can be drawn from usage analysis during participation processes. For the start, studies on publicly documented participation procedures can serve as the initial data basis.

The availability of external service providers through the marketplace reduces the effort for initiators to develop as well as maintain the participation process on the platform long-term. Our configurator concept introduces initiators to the specialized technologies virtual reality and augmented reality in the context of public participation, which can increase acceptance and use of mixed reality in the long term.

Appendix

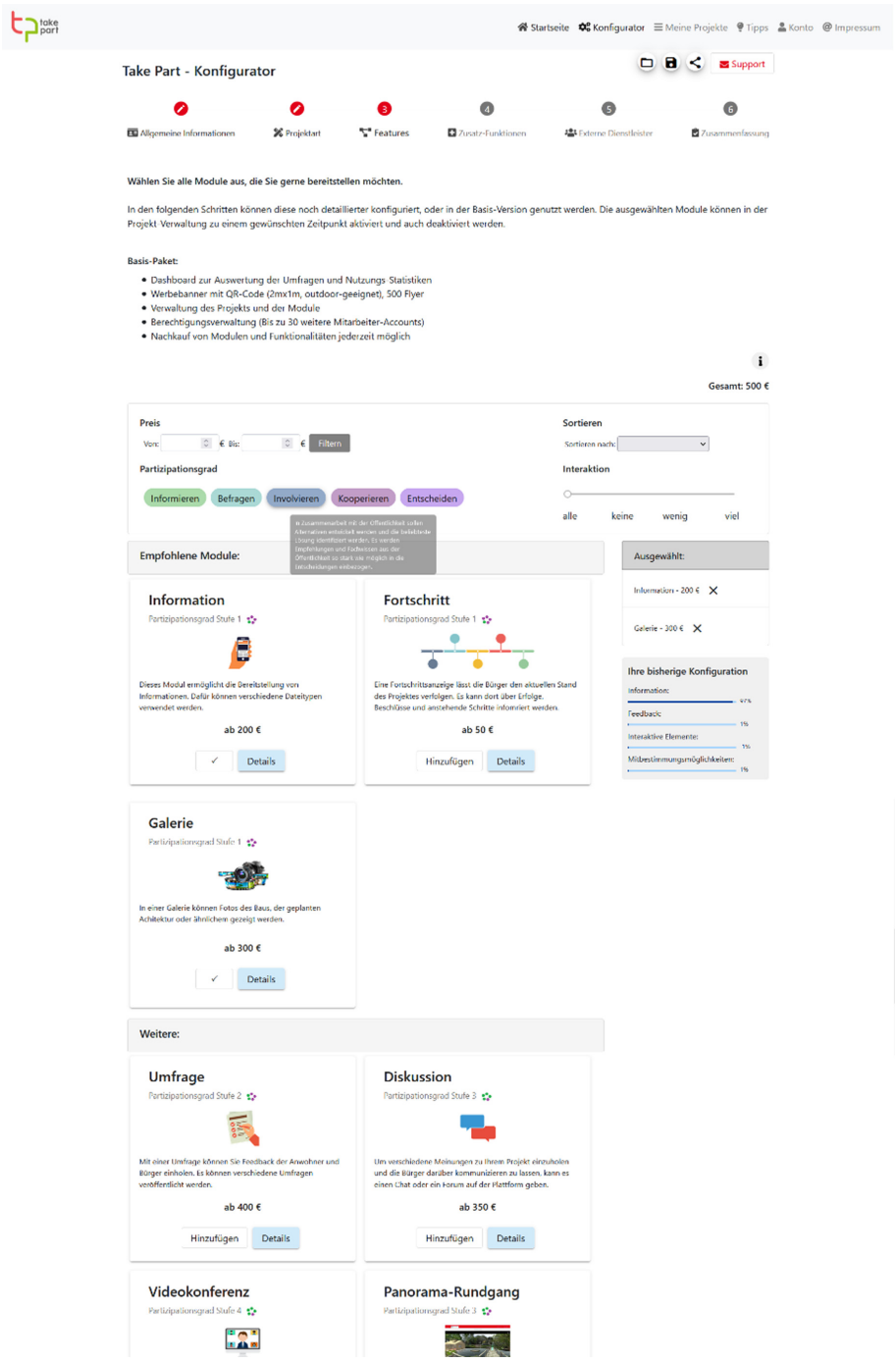

Fig. A. Step 3 (Module selection)[16].

16 https://github.com/LenaS16/TakePartPaper/blob/b2796b0e68bdf9b7d06744157da64bfe09d850de/Modulauswahl-Screenshot.png (last accessed 2021/10/29).

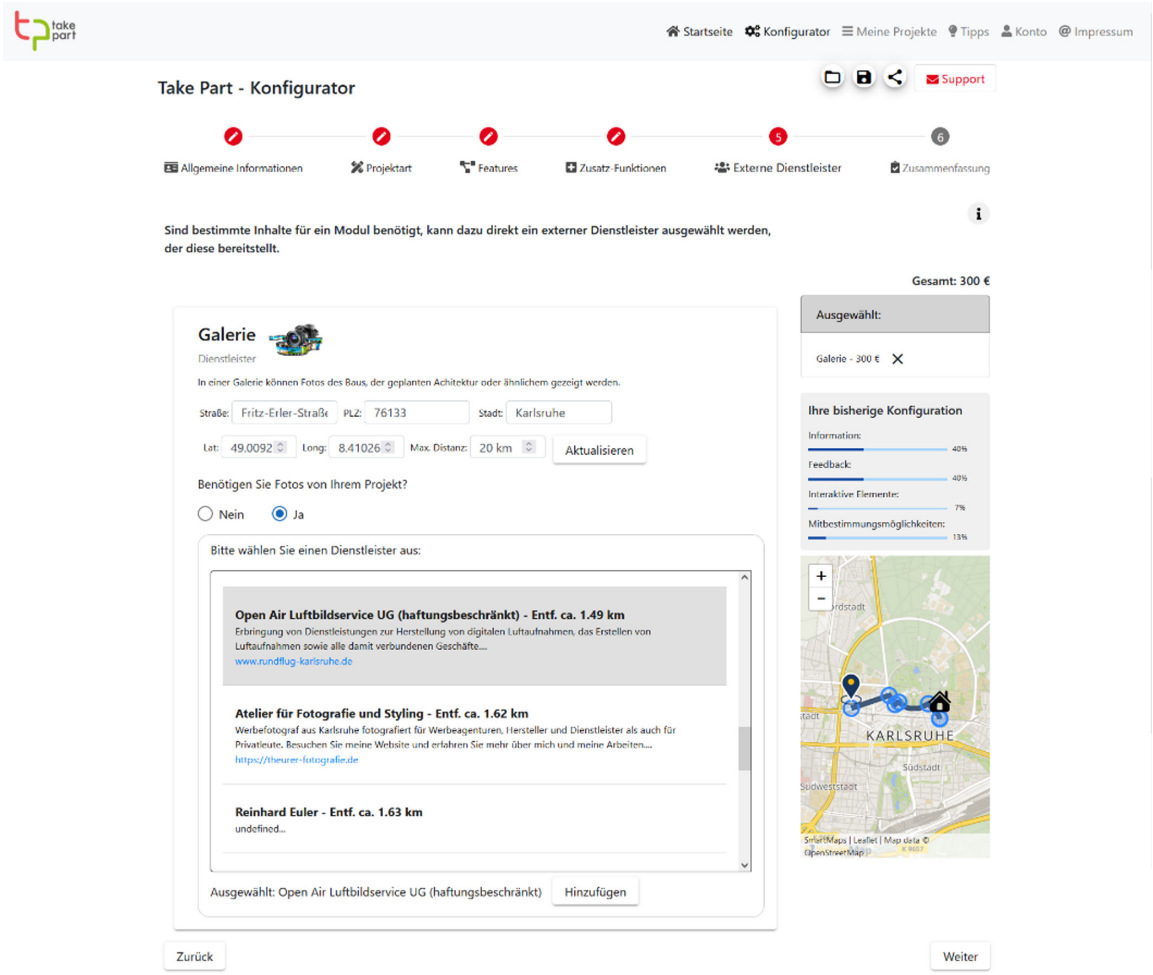

Fig. B. Step 5 (External service providers)[17].

References

1. Zepic, R., Dapp, M., Krcmar, H.: Participatory budgeting without participants: Identifying barriers on accessibility and usage of German participatory budgeting. In: 2017 Conference for E-Democracy and Open Government (CeDEM), pp. 26–35 (2017)
2. Wolf, M., Söbke, H., Wehking, F.: Mixed Reality media-enabled public participation in urban planning. In: Jung, T., tom Dieck, M.C., Rauschnabel, P.A. (eds.) Augmented Reality and Virtual Reality. PI, pp. 125–138. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-37869-1_11
3. Van Leeuwen, J.P., Hermans, K., Jylhä, A., Quanjer, A.J., Nijman, H.: Effectiveness of virtual reality in participatory urban planning: A case study. In: Proceedings of the 4th Media Architecture Biennale Conference, pp. 128–136 (2018)
4. Goudarznia, T., Pietsch, M., Krug, R.: Testing the effectiveness of augmented reality in the public participation process: a case study in the city of bernburg. J. Digit. Landsc. Archit. **2**, 244–251 (2017)
5. International Association for Public Participation: IAP2 Spectrum of Public Participation (2018)

[17] https://github.com/LenaS16/TakePartPaper/blob/b2796b0e68bdf9b7d06744157da64bfe09d850de/Externe%20Dienstleister-Screenshot.png (last accessed 2021/10/29).

6. Alfaro, C., Gomez, J., Lavin, J.M., Molero, J.J.: A configurable architecture for e-participatory budgeting support. JeDEM-eJ. eDemocr. Open Gov. **2**, 39–45 (2010)
7. Cindio, F., Peraboni, C.: Fostering e-participation at the urban level: outcomes from a large field experiment. In: Macintosh, A., Tambouris, E. (eds.) ePart 2009. LNCS, vol. 5694, pp. 112–124. Springer, Heidelberg (2009). https://doi.org/10.1007/978-3-642-03781-8_11
8. Chuah, S.H.-W.: Why and who will adopt extended reality technology? Literature review, synthesis, and future research agenda. Lit. Rev. Synth. Futur. Res. Agenda. (2018)
9. Wirtz, B.W., Daiser, P., Binkowska, B.: E-participation: a strategic framework. Int. J. Public Adm. **41**, 1–12 (2018)
10. Macintosh, A., Coleman, S., Schneeberger, A.: eParticipation: the research gaps. In: Macintosh, A., Tambouris, E. (eds.) ePart 2009. LNCS, vol. 5694, pp. 1–11. Springer, Heidelberg (2009). https://doi.org/10.1007/978-3-642-03781-8_1
11. Nelimarkka, M., et al.: Comparing Three Online Civic Engagement Platforms using the Spectrum of Public Participation (2014)
12. Zissis, D., Lekkas, D.: Securing e-Government and e-Voting with an open cloud computing architecture. Gov. Inf. Q. **28**, 239–251 (2011)
13. Christina, K., Tsarchopoulos, P., Simitopoulos, D., ASI, A.G.Q.: Deliverable 5.1. 1 Body of Knowledge about the Migration of Public Services into the Cloud (2015)
14. Lönn, C.-M., Uppström, E.: Core aspects for value co-creation in public sector. In: Twenty-first Americas Conference on Information Systems. Association for Information Systems, Puerto Rico (2015)
15. Chen, J., et al.: Wireframe-based UI design search through image autoencoder. ACM Trans. Softw. Eng. Methodol. **29**, 1–31 (2020)
16. Bevan, N., Kirakowski, J., Maissel, J.: What is usability. In: Proceedings of the 4th International Conference on HCI (1991)
17. Nielsen, J.: What Is Usability? In: User Experience Re-Mastered, pp. 3–22. Elsevier (2010). https://doi.org/10.1016/B978-0-12-375114-0.00004-9
18. Abbasi, E.K., Hubaux, A., Acher, M., Boucher, Q., Heymans, P.: The anatomy of a sales configurator: an empirical study of 111 cases. In: Salinesi, C., Norrie, M.C., Pastor, Ó. (eds.) CAiSE 2013. LNCS, vol. 7908, pp. 162–177. Springer, Heidelberg (2013). https://doi.org/10.1007/978-3-642-38709-8_11
19. Lee, Y.-J.: Card-Based User Interface on Smart-Phone. J. Digit. Converg. **15**, 555–561 (2017)
20. Rodrigues, J.M.F., et al.: Adaptive card design UI implementation for an augmented reality museum application. In: Antona, M., Stephanidis, C. (eds.) UAHCI 2017. LNCS, vol. 10277, pp. 433–443. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-58706-6_35
21. Roy, R., Warren, J.P.: Card-based design tools: a review and analysis of 155 card decks for designers and designing. Des. Stud. **63**, 125–154 (2019)
22. Tandel, S., Jamadar, A.: Impact of progressive web apps on web app development. Int. J. Innov. Res. Sci. Eng. Technol. **7**, 9439–9444 (2018)
23. Gavrilă, V., Băjenaru, L., Dobre, C.: Modern single page application architecture: a case study. Stud. Informatics Control. **28**, 231–238 (2019)
24. Marakas, G.M.: Decision Support Systems in the 21st Century, vol. 134. Prentice Hall, Upper Saddle River, NJ (2003)
25. Bonczek, R.H., Holsapple, C.W., Whinston, A.B.: Foundations of Decision Support Systems. Academic Press (2014)
26. Pfeiffer, J., Benbasat, I., Rothlauf, F.: Minimally restrictive decision support systems. In: Thirty Fifth International Conference on Information and Systems (2014)
27. Pfeiffer, J., Scholz, M.: A low-effort recommendation system with high accuracy. Bus. Inf. Syst. Eng. **5**, 397–408 (2013)
28. Wang, W., Benbasat, I.: Interactive decision aids for consumer decision making in e-commerce: the influence of perceived strategy restrictiveness. MIS Q. **33**, 293–320 (2009)

29. Robert, G., Hockey, J.: A motivational control theory of cognitive fatigue. In: Ackerman, P.L. (ed.) Cognitive Fatigue: Multidisciplinary Perspectives on Current Research and Future Applications., pp. 167–187. American Psychological Association, Washington (2011). https://doi.org/10.1037/12343-008
30. Gourville, J.T., Soman, D.: Overchoice and assortment type: when and why variety backfires. Mark. Sci. **24**, 382–395 (2005)
31. Brooke, J.: Others: SUS-A quick and dirty usability scale. Usability Eval. Ind. **189**, 4–7 (1996)
32. Olson, G.M., Duffy, S.A., Mack, R.L.: Thinking-out-loud as a method for studying real-time comprehension processes. In: Kieras, D.E., Just, M.A. (eds.) New Methods in Reading Comprehension Research, pp. 253–286. Routledge (2018). https://doi.org/10.4324/9780429505379-11
33. Schramm, L.T.: Gestaltung eines geführten Konfigurationsprozesses einer Bürgerpartizipations-Plattform für Bauprojekte (2021). https://ilin.eu/wp-content/uploads/2021/06/Bachelorthesis-Lena-Schramm.pdf
34. Bordeleau, F., Sillitti, A., Meirelles, P., Lenarduzzi, V.: Open Source Systems. Springer (2019). https://doi.org/10.1007/978-3-030-20883-7
35. Kaiser, R.: Qualitative Experteninterviews: Konzeptionelle Grundlagen und praktische Durchführung. Springer-Verlag (2014)
36. Fegert, J., et al.: Take Part Prototype: Creating New Ways of Participation Through Augmented and Virtual Reality. In: 29th Workshop an Information Technologies and Systems. WITS, Munich (2019)
37. Fegert, J., et al.: Ich sehe was, was du auch siehst. Über die Möglichkeiten von Augmented und Virtual Reality für die digitale Beteiligung von Bürger: innen in der Bau-und Stadtplanung. HMD Prax. der Wirtschaftsinformatik. 1–16 (2021)

KNOWLEDGE ALL AROUND ME: COMPARING THE EFFECT OF VR, TEXT AND DESKTOP ON LEARNING OUTCOMES

Complete Research

Stejskal, Tobias, Justus Liebig University Giessen, Giessen, Germany, tobias.stejskal@wi.jlug.de
Kethüda, Kübra, Justus Liebig University Giessen, Giessen, Germany
Pfeiffer, Jella, Justus Liebig University Giessen, Giessen, Germany, jella.pfeiffer@wi.jlug.de

Abstract

With the advent of virtual reality (VR), immersive learning environments are considered as viable e-learning environments. Yet, there is still no clarity on the long-term success with VR when learning. We examine the short-term and long-term learning outcomes between an illustrated text, 2D video, and VR. This is achieved through an experiment in which the effects of the three technologies on learning outcomes were measured immediately and 14 days after the learning phase. In the short-term, VR had a larger effect on subjectively and objectively measured knowledge gain as well as on motivation than the two other learning environments. In the long-term, VR did outperform the 2D video material on the desktop only when measured objectively. Our results imply that VR can transfer knowledge to the long-term better than other learning environments but more effort needs to be made to make the learning success more obvious on a subjective level.

Keywords: Virtual Reality, Head-mounted Displays, Education, Learning, Motivation.

1 Introduction

Even though Virtual Reality (VR) technology has improved steadily over the last 60 years, its areas of application are still far removed from the everyday lives of many people. Yet, comparing first versions of consumer hardware from 2013 to the current wave of applications, an evolution is visible. One sector that one might intuitively assume to be able to exploit added value from the use of VR, due to the engaging and vivid nature of the VR technology, is the education sector (Huang and Liaw, 2011; Keengwe and Onchwari, 2011). Currently, mobile devices like tablets and laptops are sought after in the field of e-Learning as they provide the additional benefit of enabling remote learning capabilities (Ali, 2020). However, the use of VR could achieve even better learning outcomes (Freina and Ott, 2015; Hamilton et al., 2021; Kamińska et al., 2019; Kavanagh et al., 2017; Wu, Yu, and Gu, 2020), as is also supported by Multimedia Learning Theory (Mayer and Moreno, 1998). VR is a way to perceive digital content immersively and offers possibilities to convey complex information. This is because any environment can be created in VR and thus all factors, such as the laws of physics, sensory impressions, and specific events are predetermined and can be controlled.

As consequence, primarily complex, expensive or risky applications and teaching scenarios are being simulated to introduce them easily into the teaching process (Hamilton et al., 2021; Huang and Liaw, 2011; Radianti et al., 2020; Wu, Yu, and Gu, 2020). Processes can be artificially slowed down (Mantovani, 2001) or visually enhanced (Tredinnick et al., 2014) to give learners the best possible impression. From

molecules to interstellar representations, any real or abstract content can be presented (Pantelidis, 2010). Furthermore, dangerous, expensive or impractical scenarios can be rehearsed preemptively without danger and pressure to succeed (Pantelidis, 1996). Various examples for suitable environments exist in the field of medical training (Lungu et al., 2020; McCloy and Stone, 2001), which entail both risks to patients and expensive equipment.

It therefore seems that research has focused on studying the advantages of VR in delicate and dangerous scenarios (like in medicine, anxiety treatment in psychotherapy or military training) or environments that cannot be accessed otherwise (the universe or the inner space of molecules). We, in contrast, want to analyze the effect of presenting learning content in VR that is neither delicate nor dangerous, as this should represent a large majority of educational topics. Focus of this paper is thus everyday content that might, for example, be taught at school but also for personal education in our everyday lives. We therefore chose knowledge about the biological functioning of the Coronavirus as training content. Furthermore, we want to highlight the comparison of VR with standard technology, that is usually applied for learning, in order to be able to analyze whether there is a gain when using immersive VR. To the best of our knowledge, results in regard to immersive VR learning benefits are leaning towards a small effect size (Hamilton et al., 2021; Wu, Yu, and Gu, 2020). As Hamilton et al. (2021) point out, VR needs to show a tangible benefit in learning outcomes compared to less immersive and traditional teaching methods. With head-mounted displays (HMD) producing mixed results on learning performance (Hamilton et al., 2021), the key to achieving a better result is presumed to be the quality of the learning experience (Wu, Yu, and Gu, 2020). We therefore decided to compare footage from a highly immersive VR documentary with the media that is currently commonplace in education: illustrated text and 2D video on an ordinary desktop PC. Our research question is therefore: What are the differences in short and long-term knowledge gain and motivation between Virtual Reality, 2D Video and illustrated text? We conducted an experiment that had participants learn in one of the three media and measured their knowledge increase directly after and also two weeks after being exposed to the learning material. We also ensured that learning success is measured from different perspectives: Objectively by a quiz, subjectively by self-reporting in a questionnaire, and by asking about their motivation to further learn about the learning content. By conducting our experiment, we were able to show that VR increases learning success when measured with an objective quiz in the short-term when compared to both the text and 2D video treatment, as well as in the long-term when compared to the 2D video treatment on the desktop PC. The knowledge increase is also felt subjectively when measured shortly after the learning phase, but it does not translate into a subjectively perceived knowledge increase in the long-term. The same holds for motivation, which is higher after having learned in VR than it is for the other technologies, but this effect seems to diminish over time.

From a research perspective, we contribute to the recent call by Hoffmann and Pfeiffer (2021) to measure learning outcomes on different operationalizations of learning outcome because no congruent picture on the effect on learning outcomes could be found so far. Our results show good effects on the short-term on all measures. In the long-term, however, no effects on the subjective measures are found. Thus, it seems that although knowledge does increase, it is not perceived by users in the long-term. Researchers and practitioners need to think how to make the positive learning outcomes more obvious and impressing to learners. This might also help for a broader distribution and usage of VR as learning environment which is inhibitied due to a resistance to change (Polites and Karahanna, 2012), a lack of supporting infrastructure and a lack of access to alternatives (Ali et al., 2014; Buckingham, 2007; Lawrence and Tar, 2018).

2 Theory and Background

2.1 Multimedia Learning

We draw our arguments for the effect of VR on learning outcome mainly from Multimedia Learning Theory (Mayer and Moreno, 1998). For multimedia learning it can be assumed that two channels exist for processing information: auditory and visual channels. The *Multimedia Representation Principle* states that

by presenting an explanation using two modes of representation rather than a single one, participants are significantly more likely to remember the information (Hasselhorn and Gold, 2013; Mayer and Moreno, 1998) and to productively solve a transfer learning task (Mayer and Moreno, 1998). By learning through multiple channels concurrently, the chance of remembering information increases compared to information that is only provided in a single format (Hasselhorn and Gold, 2013; Mayer, 2002). Participants are able to build two different mental representations to base their understanding on and then interconnect them to form a unified representation (Hasselhorn and Gold, 2013; Mayer and Moreno, 1998). However, both channels can only be utilized at a limited rate and capacity while remaining functional.
Learning is achieved by first selecting the information from the provided verbal and visual input. Based on this, the information is structured to obtain both a text-based and image-based model of the concept being explained. Having both the corresponding words and visual representation in working memory at the same time facilitates the construction of referential links between them (Hasselhorn and Gold, 2013; Mayer and Moreno, 1998) and is coined the *Contiguity Principle* (Mayer and Moreno, 1998). The *Split-Attention Principle* (Mayer and Moreno, 1998) states that words should be imparted as audio rather than in writing (Hasselhorn and Gold, 2013). The preceding principles differ in their effectiveness between students due to a learner's personality, preferred learning type (Hasselhorn and Gold, 2013) and their level of knowledge and ability (Hasselhorn and Gold, 2013; Mayer and Moreno, 1998). Experienced students may for example be able to think up their own visual representation of verbally presented information and even retain it in visual working memory longer and more accurately, which further promotes the learning effect (Hasselhorn and Gold, 2013; Mayer and Moreno, 1998). This is also called the *Individual Differences Principle* by Mayer and Moreno (1998). The *Coherence Principle* suggests that a more coherent presentation is better if it highlights key concepts and relevant illustrations rather than a more extensive summary (Mayer and Moreno, 1998). As a result, students are more likely to select relevant information from shorter presentations and form an organized understanding (Hasselhorn and Gold, 2013; Mayer and Moreno, 1998).

2.2 Virtual Reality

According to Steuer (1992) the key to defining VR is the concept of telepresence. In an unmediated reality the user experiences his immediate physical surroundings. By introducing a technology that mediates the environment the user feels both presence in the physical environment and telepresence in the virtual one. Therefore any environment that evokes telepresence in its user is a virtual reality (Steuer, 1992). The experienced, subjective telepresence heavily depends on the system's degree of immersion (Schultze, 2010). Immersion is defined as "the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding and vivid illusion of reality to the senses of a human participant" (Slater et al., 1996, p.165). It is limited by the applied technology and therefore objective and measurable (Bowman and McMahan, 2007; Slater et al., 1996). Beginning with the term inclusiveness, that describes the extent to which the person experiencing VR is isolated from reality itself, the level of accommodation for the range of human senses can be described as the extensiveness of the experience. The extent of the field of vision is called surrounding and the available interaction possibilities with the virtual environment are referred to as interactivity. Lastly, vividness is introduced as a construct of the grade of detail present in the simulation, such as the displayed resolution, the level of quality of the included content and richness of the environment (Slater et al., 1996).
Rauschnabel et al., 2022 utilizes telepresence as a VR-Continuum in their XReality framework. On this range of VR applications, environments with very high telepresence represent the upper end. These applications are intended to represent an environment that is virtually indistinguishable from reality. Here, the experience of the application can be an end in itself, for example in the case of VR games in which the user's motivation and goal is to experience the VR environment itself (Hassenzahl, 2018). In contrast to that exist atomistic VR applications. They can be seen as tools and means to an end. They do not solely serve as an experience, but instead enable the user to perform a function or fulfill a use case,

such as viewing a construction blueprint (Shahab, Ghazali, and Mohtar, 2021). Here the user's perceived telepresence is not as relevant as the VR application's provided utility (Hassenzahl, 2018).

The current wave of VR devices is driven by HMDs that pursue the goal of representing a virtual world as an immersive experience through stereoscopic, surrounding vision that dynamically tracks the head rotation and translation (Brooks, 1999; Pan and Hamilton, 2018). Now that this technology is finally widely available to consumers (Xi and Hamari, 2021), its general adoption and use for training and education becomes feasible (Pan and Hamilton, 2018).

2.3 Related Work from e-Learning

Conventional teacher-centric education methods are not well suited for the increased demand that the education system is facing in recent years (Somayeh et al., 2016). By utilizing the benefits of digital technology, learning can happen over a distance (Banas and Emory, 1998) and become student-centric (Basak, Wotto, and Belanger, 2018; Bencheva, 2010). E-Learning provides students with increased autonomy, self-direction, and flexibility (Banas and Emory, 1998; Basak, Wotto, and Belanger, 2018; Somayeh et al., 2016), although sufficient self-discipline is necessary because of this freedom (Bencheva, 2010). As Papanis (2005) notes, it therefore represents a faster, cheaper alternative for more people that offers clear accountability to all participants involved.

To successfully utilize e-Learning, a combination of technology, digital content and instructions is needed (Basak, Wotto, and Belanger, 2018). E-Learning technology is a tool to deliver content to learners.

To further enrich the learning experience, the use of gamified learning environments is a viable option (Gros, 2007). According to Pan, Cheok, et al. (2006) VR based virtual learning environments can be an effective means to elevate both teaching materials and methods. For example, by utilizing a serious game, Hoffmann and Pfeiffer (2021) were able to significantly outperform paper-based learning materials. Since interactivity is a direct measure of control of the virtual environment in VR, parallels can be drawn to the self-directed nature of e-Learning. In addition, the extensiveness of VR makes it easier to convey the instructions and guidance needed, as more senses can be appropriately addressed.

Based on recent reviews (Hamilton et al., 2021; Wu, Yu, and Gu, 2020) we build on existing e-Learning research in multiple ways. Firstly, we improve on a set of publications that rely only on a single comparison group (e.g. Alhalabi, 2016; Fogarty, McCormick, and El-Tawil, 2018; Harrington, Kavanagh, Quinlan, et al., 2018; K. Babu et al., 2018; Makransky, Terkildsen, and Mayer, 2019; Molina-Carmona et al., 2018; Sankaranarayanan et al., 2018) by incorporating two commonplace media types, illustrated text and 2D video on a desktop computer. Secondly, we measured both the short and long-term learning outcomes in our experiment, which improves on prior research (e.g. Allcoat and Mühlenen, 2018; Harrington, Kavanagh, Wright Ballester, et al., 2018; Makransky, Terkildsen, and Mayer, 2019; Yoganathan et al., 2018). Lastly the current research does not account for objective and subjective learning outcomes, as well as motivation to learn (e.g. Allcoat and Mühlenen, 2018; Harrington, Kavanagh, Quinlan, et al., 2018; Makransky, Terkildsen, and Mayer, 2019; Yoganathan et al., 2018).

Closest to our area of interest were Smith et al. (2018) teaching medical decontamination, that compared HMD VR with desktop VR and written instructions, but were unable to find any effect directly after the experiment and when testing participants again after six months. However, Allcoat and Mühlenen (2018) compared how well a VR HMD, a textbook and desktop video performed when teaching about plant cells. They were able to show desktop video being less effective overall, but only measured directly after the experiment, focusing on the short-term effects of the chosen media.

Finally and in light of the above mentioned research gaps, this paper is meant to identify whether and to what extent learning content in VR can increase learning success compared to the widespread standard media like 2D videos on desktop screens and illustrated text in both the short-term and long-term. We do so with a learning content that is representative of many everyday instructional materials, instead of focusing on particularly well-suited VR scenarios.

2.4 Hypotheses

As VR offers a very high inclusiveness, it is likely that learners in VR will experience low distraction, which directly benefits the learning process (Hasselhorn and Gold, 2013). According to Hamilton et al. (2021) and Webster (2016), higher immersion is also better suited for cognitive learning activities. In comparison to an illustrated text, it also simultaneously conveys the learning content in two modes of presentation rather than just in a single one or one after the other. From a more theoretical perspective, VR, thus, fulfills the aforementioned *Multimedia Representation Principle*. Additionally, the *Contiguity Principle* is met by showing actions rather than describing them extensively, both when shown as a 2D video on a desktop and in VR. However, by utilizing the higher immersion of VR, the learning material can also be presented as concisely as possible, which is in accordance with the *Coherence Principle*. For instance, the depth representation in VR makes it easier to recognize spatial relationships and movements, and sizes can be better estimated than in 2D (Servos, 2000). Additionally, the more vivid natural representation has a lower abstraction (Hamilton et al., 2021), allowing for a more coherent and accurate representation than more descriptive, abstract learning content (Mayer and Moreno, 1998). The objects of the learning environment, their attributes and relations are easier to visualize and to conceptualize (Hedberg and Alexander, 1994; Huang and Liaw, 2011). Therefore VR should have a positive effect on learning when compared to less immersive technologies (Choi, Dailey-Hebert, and Estes, 2021; Kamińska et al., 2019; Kavanagh et al., 2017; Keengwe and Onchwari, 2011).

H1a: The short-term knowledge gain in VR is larger than in text form.

H1b: The short-term knowledge gain in VR is larger than with 2D video.

According to Ebbinghaus (1885) and Murre and Dros (2015), being able to recall information decreases exponentially within the first 24 hours and subsequently stagnates between the 5th and 31st day, unless what is learned is repeated. However, retention increases when multiple input channels are addressed (Hasselhorn and Gold, 2013; Mayer and Moreno, 1998; Philippe et al., 2020), which is the case for VR (Zender et al., 2018). According to Mantovani (2003), active learning with VR enables new knowledge to be dynamically matched with old knowledge, which is a prerequisite for the transfer to long-term memory (Hasselhorn and Gold, 2013). Thus, because of the multimodal encoding in VR, we propose the following hypotheses:

H2a: The long-term knowledge gain in VR is larger than in text form.

H2b: The long-term knowledge gain in VR is larger than on the 2D video.

Motivation must be regarded as a crucial factor for successful learning (Prenzel et al., 1996). According to previous studies, the motivation for using VR is comparatively higher than other technologies (Huang and Liaw, 2011; Sattar et al., 2019) as the intrinsic motivation, attitude towards learning and learning efficiency are higher. Additionally, Ankomah and Vangorp (2018) conclude that VR leads to a previously non-existent, higher engagement with the subject matter (Barfield and Hendrix, 1995; Da Costa and Nedel, 2017), while other research makes the novelty of the technology accountable for higher motivation (Huang, Rauch, and Liaw, 2010; Zavalani and Spahiu, 2012). Ankomah and Vangorp (2018) also find that VR leads to a previously non-existent, higher engagement with the subject matter due to the interactivity being beneficial in reaching a flow state. Further hypotheses result from this:

H3a: The short-term motivation gain in VR is larger than in text form.

H3b: The short-term motivation gain in VR is larger than on the 2D video.

H4a: The long-term motivation gain in VR is larger than in text form.

H4b: The long-term motivation gain in VR is larger than on the 2D video.

3 Empirical Evaluation

3.1 Experimental Design and Material

To answer the research questions, we conducted a laboratory experiment to compare the effects of presenting learning material using different technologies: presenting in VR on a Meta Quest HMD, as 2D video on a common desktop PC and through an illustrated text. We chose a between-subjects design and measured both knowledge and motivation increase in the short and long-term after the learning scenario. As teaching materials the structure and behavior of COVID-19 appeared suitable, since basic knowledge and interest can be assumed due to the presence in the media at the time. As a lack of subject-specific knowledge is necessary to generate an increase in knowledge, we chose this biological perspective on the virus at the cellular level. The availability of strong documentary (Yost, Loften, and Murdock, 2021) as a basis (see Figure 1) for our learning material was also a factor. Additionally, it is an insight that is difficult to reproduce in reality due to the microscopic perspective, which makes it well suited for a VR scenario (Hamilton et al., 2021; Wu, Yu, and Gu, 2020).

The documentary conveyed deep biological knowledge beyond what is commonly presented in everyday media about the Coronavirus. To provide consistent and high-quality learning content, we showed two different learning materials. The first learning material relates to the structure of the Coronavirus with its seven components. This part of the experiment was interactive for the VR and 2D video groups. For this purpose, a 3D animation from the German-language science magazine Spektrum.de (Fischer et al., 2021-27-02), which works both in VR and on the desktop, was used. By clicking on the numbered and highlighted areas of the virus, the labels of the components and the functions were explained. Whereas the VR and 2D video groups were shown the same 3D model, for the text group the learning material was presented as a four-page information sheet containing image excerpts of the animation with the seven virus components. All participants were asked to memorize the information and it was ensured that all available information was accessed and observed.

By combining excerpts from the critically acclaimed VR documentary “Inside COVID19” (Yost, Loften, and Murdock, 2021) we created a stereoscopic 360° video. This recombined material explains the three phases of how the Coronavirus operates inside the human body: The first phase, called endocytosis, shows virus entering the human cell. The second phase of the infection process presents the replication of the genetic information. Here, the transfer of the genetic information to the ribosomes of the cell is presented visually and auditory. Exocytosis, the third and final phase of infection, describes the the newly formed viruses exiting the human cell. The necessary excerpts were provided by the WisdomVR foundation (see Table 4).

A narrator voice with further context information was added to the video material by utilizing text-to-speech technology to adhere to the *Multimedia Representation Principle* and to make it as self-contained as possible. The VR content was then adapted for the 2D video group by removing the right-eye view and resizing the image to fit on the desktop screen. Through this process, no visual information was lost. To modify the information content as little as possible, we transferred the learning content to an illustrated text in the following form: Starting with a cover page, the topic was briefly summarized. Endocytosis, replication and exocytosis are then covered in their own sections, taken almost verbatim from the narration and illustrated with appropriate stills from the video material (similar to Figure 1). In total participants received seven pages of information about the structure and behavior of the virus as an illustrated text.

3.2 Dependent Variables and Control Variables

We measured the subjective knowledge gain after the participant had studied the learning content by asking a 1-item question on a 6-point Likert scale: “I have gained a better understanding of the mode of action of the Coronavirus through the experiment”. We asked this question again after two weeks to also measure the long-term knowledge gain (subjective). For measuring the objective knowledge gain, we

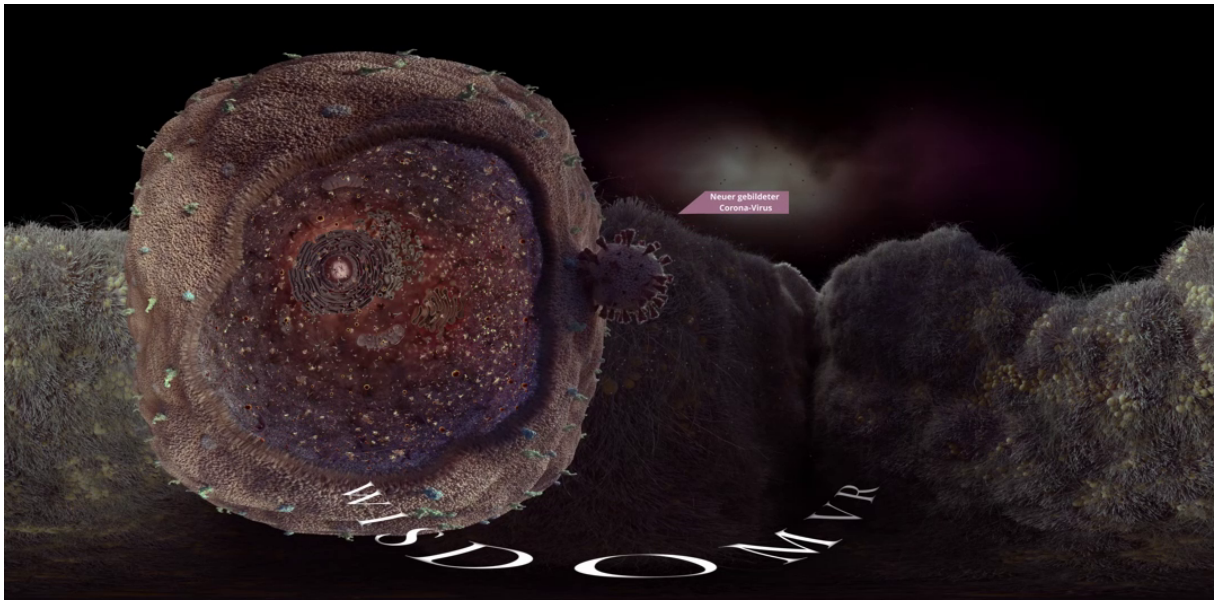

Figure 1. Still from "Inside COVID19" (Yost, Loften, and Murdock, 2021)

conducted a pre-test with a multiple-choice-based questionnaire (MCQ) (Kraiger, Ford, and Salas, 1993) on the mechanism of the COVID-19 virus before showing participants any learning material. We utilized this test as a baseline to measure against. This MCQ test consisted of ten knowledge questions with four answer options each, of which only one was correct. In addition, the non-content category "I don't know" was introduced to prevent subjects that didn't know the answer from feeling pressured to guess an answer rather than omitting the field (Converse and Presser, 1986; Katz, 1942; Menold and Bogner, 2015). According to Andrews (1984), scales with a non-content response option have a higher validity and lower method effects as well as lower error variances than scales without a non-content category. For measuring the objective short-term and long-term knowledge gain, we then created two additional MCQs, each with ten modified questions on the learning content. The questions covered the same topics but differed in terms of what information was queried. To substitute the questions, emphasis was placed on consistent complexity and a close relatedness of the addressed content. The second MCQ was used to measure short-term knowledge gain. For long-term learning it is recommended to repeat the test at the earliest two days after learning (Schmidt and Bjork, 1992). Based on Ebbinghaus (1885) and Murre and Dros (2015), recall of knowledge stagnates between day 5 and day 31. Therefore, this experiment resorted to re-measuring 14 days after the learning experience to address long-term retention (Ebbinghaus, 1885; Keith and Frese, 2008; Murre and Dros, 2015; Schmidt and Bjork, 1992). This period has been used in IS research on e-education before (see, i.e., Hoffmann and Pfeiffer (2021)). The third MCQ was utilized to measure long-term knowledge gain. All questionnaires can be found in Table 6 in the Appendix.

For each of the three knowledge tests (pre-test, short-term, and long-term) we summed up the number of right answers and multiplied that by 10. To rule out effects of the *Individual Differences Principle* (Mayer and Moreno, 1998), we computed the short-term and long-term knowledge gain by calculating the difference between each result and the pre-test. For example, a value of 40 for short-term knowledge gain (obj.), would mean the participant had answered an additional 4 questions correctly in comparison to the pre-test.

Finally, we measured motivation with a 1-item question on a 6-point Likert-scale: "I am more motivated to learn about the mode of action of the Coronavirus after completing the experiment". Finally, the demographic variables age and gender served as control variables and were asked at the beginning of the experiment in the pre-test questionnaire. We also wanted to control for the participants' experience with VR and therefore asked all participants the following two questions on a 6-point Likert scale: "I

have already experienced virtual reality glasses" and "I have frequent access to a virtual reality device". The pre-questionnaire also asked for the current mood and beliefs about the Coronavirus, educational background and whether participants had studied biological modes of action in the past.

3.3 Participants

In total, the sample consisted of 63 participants, 21 of whom were randomly assigned to each of the three groups. Among the participants were 26 university students, 2 house-wives, and 7 high-school students, with the remainder being employed. In terms of the education level the participants were quite diverse, ranging from basic school backgrounds to academic degrees. We invited only people with German language skills, no dyslexia and complete vision to be able to perceive and understand the information presented. Furthermore, participants with studies in the field of biology or medicine were excluded, as they must be assumed to have a high level of expertise on the subject matter, so that the increase in knowledge would be negligible.

3.4 Procedure

To attract participants to the experiment, two digital vouchers were raffled between all participants. The winners were drawn after the experiment had ended. At first, subjects answered the pre-questionnaire, including the pre-test and control variables. Participants were scheduled in one-hour slots and the experiment was conducted individually with each of them. The average completion time for the VR group was 45 minutes, 40 minutes for the 2D video group, and 30 minutes for text. The difference in duration is mostly due to the differing set-up and instruction times. The experimenter made sure that all treatments were exposed to the learning content itself for approximately the same amount of time. For each group, aesthetic and calming content was shown to the subjects in advance for about two minutes in their respective technology (text, 2D video, VR). The content shown was a seascape with moving water and relaxing organ music in the background for the VR and 2D video groups. The text group was presented with a single image excerpt from the same video, without background music. This warm-up period served several purposes: First, subjects had the opportunity to adjust to their technology. Second, they had the opportunity to become familiar with their environment and calm themselves so that subjects could focus on the learning content. Subsequently, the learning materials were shown, and participants were asked to memorize the contents. Additionally, the complexity of the learning material was evaluated in a qualitative manner after the experiment was over and participants were asked to clarify comments and remarks made during the experiment. Out of 63 participants, 12 did not respond to the invitation of the final long-term questionnaire or had to be removed because of not properly answering attention check questions in the long-term questionnaire. Thus, the analysis of the long-term measures was only computed with 51 instead of 63 participants.

4 Results

Table 1 shows the descriptive statistics of the dependent measures for the three treatments. As can be seen in the table, the exposure to the learning material increased knowledge for all treatments because the values are all positive. As expected, the short-term knowledge when measured objectively is higher immediately after the stimuli exposure (short-term) than in the long-term, for example 60 in comparison to 36.84 in the VR treatment. A drop in knowledge was expected when comparing short-term vs long-term knowledge gain. Yet, we cannot completely rule out that the knowledge test for the long-term evaluation was perceived harder than the short-term one. In any case, as we are interested in the differences between treatments, this will not harm our analysis.
The drop in knowledge gain cannot be observed when knowledge gain is rated subjectively by the participants. The values stay astonishingly constant (for example VR had 5.29 in the short-term vs. 5.32 in the

		VR	2D video	Text
Short-Term Know. Gain (obj.)	mean (min/max)	60 (0/100)	45.24 (10/80)	44.29 (0/90)
	std. dev.	29.33	21.59	24.20
Long-Term Know. Gain (obj.)	mean (min/max)	36.84 (0/80)	17.86 (-30/70)	25.56 (-10/80)
	std. dev.	24.51	23.59	25.02
Short-Term Know. Gain (subj.)	mean (min/max)	5.29 (3/6)	4.67 (2/6)	4.81 (3/6)
	std. dev.	0.85	1.28	0.98
Long-Term Know. Gain (subj.)	mean (min/max)	5.32 (3/6)	4.86 (2/6)	4.83 (4/6)
	std. dev.	0.89	1.23	0.92
Short-Term Motivation	mean (min/max)	4.33 (3/6)	3.29 (1/6)	3.71 (2/6)
	std. dev.	1.06	1.68	1.01
Long-Term Motivation	mean (min/max)	3 (1/5)	2.43 (1/5)	2.61 (1/5)
	std. dev.	1.15	1.34	1.29
age	mean (min/max)	27.14 (17/34)	23.86 (1734)	25.05 (17/35) (1/5)
gender	%female	52.38	57.14	71.43

Table 1. Descriptive Statistics.

long-term), showing the high relevance of measuring knowledge gain from different perspectives (subjectively and objectively). Finally, motivation drops between the short-term and long-term measurements. This can also be expected, as the exposure to the learning content should lose its effects after a while.

For all statistical tests, we computed ordinary least square (OLS) regressions with the treatment as the independent variable. We used the VR treatment as the reference category. Robust standard errors were used in the regressions when needed to account for heteroscedasticity, based on the Breusch–Pagan test (Cohen, West, and Aiken, 2014). This was only necessary for the dependent variable short-term motivation. Furthermore, we bootstrapped the results with a sample size of 5,000 when residuals were non-normally distributed (Efron and Tibshirani, 1994; Pek, Wong, and Wong, 2018). This was the case for the short-term and long-term subjective knowledge gain. Table 2 shows the results of the three regressions for the short-term measures and Table 3 those for the long-term measures. All our hypotheses were directed and therefore we tested the p-coefficients one-tailed. We found significant effects on short-term knowledge, both when measured objectively and subjectively, which supports hypotheses 1a and 1b. For example, in the VR treatment, participants are estimated to have a knowledge gain of about 14.76% (1.476 more questions answered correctly of out the ten questions when compared to the performance of the pretest) than the 2D video treatment and 15.71% more than the text treatment. For the subjective knowledge gain measurement, the gain is estimated to be 0.62 higher in the VR treatment on the 6-point Likert scale than in the 2D video treatment and 0.48 higher than in the text treatment. Also, hypotheses 3a and 3b can be supported, finding a positive effect of VR on short-term motivation when compared with the two other treatments. Additionally we tested for differences between the text and the 2D video treatment, although we did not hypothesize any differences. And, indeed, we did not find any significant difference with respect to any of the six dependent variables.

Table 3 shows the results regarding the hypotheses about long-term consequences. Here, the VR treatment performs better than the 2D video treatment when knowledge is measured objectively, but not when it is measured subjectively (partial support of H2b). Yet, this effect is not found when we compare the knowledge gain of the VR treatment with that of the text treatment (no support of H2a). Furthermore, hypotheses 4a and 4b need to be rejected because there is no effect on long-term motivation

As can be seen in table 1, there were slightly more females in the test treatment, yet gender can be assumed to be equally distributed over the three treatments ($\chi^2 = 1.72, p = 0.42$). There was also no different between treatments with regard to VR access and VR experience. However, the mean age of participants in the VR treatment was significantly lower than in the 2D Video treatment. To further assess the robustness

	Short-T. Know. Gain (obj.)		Short-T. Know. Gain (subj.)		Short-T. Motivation	
	coef. (std. er.)	p (one-tailed)	coef. (bootstr. std. er.)	p (one-tailed)	coef. (bootstr. std. er.)	p (one-tailed)
2D video	-14.76 (7.79)	0.03*	-0.62 (0.33)	0.03*	-1.05 (0.43)	0.01*
Text	-.15.71 (7.79)	0.02*	-0.48 (0.28)	0.05*	-0.62 (0.32)	0.03*
N	63		63		63	
R^2	.08		.06		0.11	

Table 2. OLS Regression Results Measuring the Treatment Effects on Short-Term Learning Outcomes.

	Long-T. Know. Gain (obj.)		Long-T. Know. Gain (subj.)		Long-T. Motivation	
	coef. (std. er.)	p (one-tailed)	coef. (bootstr. std. er.)	p (one-tailed)	coef. (std. er.)	p (one-tailed)
2D video	-18.98 (8.61)	0.02*	-0.56 (0.39)	0.08	-0.57 (0.44)	0.10
Text	-11.29 (8.04)	0.08	-0.12 (0.34)	0.35	-0.39 (0.41)	0.18
N	51		51		51	
R^2	.08		.05		0.04	

Table 3. OLS Regression Results Measuring the Treatment Effects on Long-Term Learning Outcomes.

of our results, we therefore also computed robust OLS regressions with the control variables age, gender, VR experience and VR access. The results were robust regarding the inclusion of these control variables.

5 Discussion and Conclusion

Our empirical evaluation highlights the positive effect of presenting the learning content in VR in comparison to showing it as 2D video on the desktop and printed in text and pictures on paper when it comes to knowledge gain and motivation. This effect can be seen in an estimation of a knowledge increase of about 15% in the VR treatment compared to the other two treatments. This effect also remains in the long-term when measured objectively, with and increase of about 19% in VR compared to the 2D video treatment and about 12% compared to the text treatment. Transferring knowledge to the long-term is a challenge but promising attempts were recently made by Hoffmann and Pfeiffer (2021) with serious games for ordinary mobile phones. In this study, the difference between knowledge in the game versus the paper-based material learning treatment groups was a bit weaker than in our setup (about 8% performance increase in an objective knowledge test while we have between 12% and 19%), with the increase in Hoffmann and Pfeiffer (2021) being measured two weeks after the teaching period. Our results are thus promising and therefore it might be an interesting further attempt to combine serious games with VR to leverage both positive effects of gaming and VR in the educational domain.

The results of this study have to be interpreted in light of several limitations. First, there were some technical problems related to the VR experience that were stated in a short qualitative interview that followed the experiment. In general, 66.67% of the subjects in the VR group experienced at least one problem while using the technology. These problems can be summarized into general problems with the VR device, problems during the first and problems during the second phase of the experiment. General issues included partially blurred images (3 out of 21 people), repeatedly leaving the bounded VR safe space (2 out of 21), orientation issues in the VR environment (4 out of 21), and fatigue caused by virtual reality (1 out of 21). During the first phase of the learning materials difficulties were encountered while interacting with the 3D animation of the virus' structure while operating the controllers. 19.05% of VR

subjects found the operation of the buttons problematic, and for 66.67%, the virus zoomed in sufficiently to require a reset to continue reading the fonts. During the method of operation material 4 out of 21 subjects in the VR group mentioned that they looked around the 360° video and could see some text descriptions for far too short a time. This was confirmed by observing the participants' field of vision in the Quest app. Such problems, according to studies, constrain knowledge acquisition (Huang, Rauch, and Liaw, 2010; Le, Pedro, and Park, 2015), which leads us to believe that the results could be stronger if the handling of the technology was less error prone. These issues could be controlled and remedied in a subsequent study by recruiting only individuals for the VR group who are trained in the use of VR and have a VR device available to them to ensure exposure to the subject matter using the same medium. Alternatively, a more extensive introductory phase with specific practice tasks for each technology could significantly limit these issues. This could also provide insights into the question posed by Kavanagh et al. (2017) of whether motivation for the subject matter is based on the novelty of the technology or whether imparting knowledge with HMDs permanently increases motivation for the subject matter.

Second, we had 12 drop outs after our short-term evaluation. The drop out rates were not evenly distributed across the groups with 7 drop out of the 2D video group and 2 in the VR and 3 in the text group. We cannot rule out that this eventually effected our results because of quite small group size for 2D video for the long-term measure. By paying a guaranteed fee for participating in the long-term evaluation, one might mitigate this problem in future experiments. Further limitations can be derived from remarks the participants made after the experiment was over. Future work may also include a larger number of participants. Some found the synthetic voice to be annoying, and its speaking cadence and pace were criticized. The speaking pace is mainly addressed by the VR group, so that in a follow-up study a professional speaker would have to be recorded. This way a natural voice and slower speaking rate could be ensured. Thus, the effects of the VR and the 2D video treatments might be understated because of the artificial voice. Additionally subjective knowledge gain and motivation are single items on a 6 point likert scale, which in future research should be expanded. Future work might also go beyond simple recall and incorporate a revision of Bloom's Taxonomy (Anderson and Krathwohl, 2021). Lastly the knowledge MCQs could be randomly ordered for each participant, reducing the reliance on the matching difficulty levels of each test.

This paper makes several contributions: First, we provide a clean comparison between learning outcomes of high-immersive VR and two widely used educational media that offer lower immersion (2D video and printouts with text and pictures). In particular, we made every effort to guarantee the learning content itself being constant, while also suitable for each technology. Second, the results presented are convincing as VR performed strongly in the short-term. Furthermore, we can show a positive effect for objective knowledge gain when we compare VR with 2D video and at least a positive tendency for the comparison of VR to text. This is promising because a long-term effect might be hard to achieve in the given short amount of learning time and with the rather demanding learning material that we provided. Additionally we are trying to teach declarative knowledge (Radianti et al., 2020), which Parmar et al. (2016) conclude to be harder to achieve in VR than to be instructed in applying a method. Third, with this study, we hope to contribute to the current body of knowledge on the use of VR in the educational system by highlighting the need to measure both short-term and long-term effects, as well as to use different measures, particularly subjective and objective ones. Our results indicate that both measures might not behave congruently. In our case the subjective long-term knowledge gain did not reflect the drop in objective performance.

While we were able to show a positive effect of VR on learning outcomes, further obstacles exist for the actual deployment of VR. In addition to the complex creation of VR content, the distribution of VR HMDs must also increase significantly. But Polites and Karahanna (2012) highlighted the inertia of technological adoption because of perceived sunken costs, transition costs and the habit of using a particular system. Accordingly, only the combination of all factors will lead to a change in thinking: Research results that show the added value, availability of consumer devices at attractive prices, and widespread use.

	Chapter “Prepare”	Chapter “Infected”	Chapter “Survive”	Chapter “Remember”
Timestamps	8:40 - 9:00 7:24 -07:50	0:25 - 0:49 7:05 - 7:45	0:25 - 0:49 4:27 - 4:54	0:24 - 1:08

Table 4. Documentary Excerpts.

6 Appendix

Pre-test: Knowledge (obj.)
How many phases does the Coronavirus cycle consist of in a cell? (6, 3, 1, 7, I do not know) What is the genetic information of the Coronavirus? (RNA, DNA, Ribosome, Enzyme, I do not know) One of the following building blocks is not a component of Coronavirus. Which one? (E-protein, M-protein, Protective sleeve, Golgi apparatus, I do not know) How does the Coronavirus replicate itself? (by dividing, by transmitting the genetic information to the ribosome, by duplicating the genetic information independently, by attacking the T-cells, I do not know) What is the first phase of the Coronavirus cycle? (Replication, Endocytosis, Duplication, Exocytosis, I do not know) What is the carrier of a virus called? (Host, Guest, Tapper, Stranger, I do not know) As what do the ACE2-receptors serve for the Coronavirus? (As an impulse to release the genetic information, Docking site to eject from the cell, Docking site to get into the cell, Protection not to be attacked by antigens, I do not know) To what does the Coronavirus owe its spiky shape to? (Receptors, Spike-protein, Ribosome, Z-Protein, I do not know) The body temperature rises to fever during an illness with the Coronavirus, due to: (The intermediate killing of cells by the virus, The separation of the proteins Z and N, The tearing of cell walls by the virus, The fight against the virus by the immune system, I do not know) What are the roles of the spikes on the Coronavirus? (Occupying the surface of the cell and spreading to human cells, Duplicating genetic information in the cell, Producing new virus particles, Merging with other viruses and thereby replicating, I do not know)
Pre-test: VR Experience {control}, 6-point Likert Scale
I have already experienced virtual reality glasses. I have frequent access to a virtual reality device.
Short-Term Evaluation: Knowledge (objective)
The Coronavirus enters the... (Pharynx cells, Nerve cells, Nerve glial cells, Endothelial cells, I do not know) The third part of the Coronavirus’ cycle is... (Replication, Endocytosis, Duplication, Exocytosis, I do not know) After penetration of the Coronavirus into the cell... (The virus retains its shape with spikes, The virus forms a capsular envelope (invaginated vehicle), The cell turns black, the cell dies immediately, I do not know) Which component of the cell contributes to the copying of viral RNA? (Endoplasmic reticulum, Mitochondria, Ribosome, Golgi apparatus, I do not know) Replication describes... (docking of the virus to the receptors of a cells, copying RNA from the virus into the cell, mutating the virus in the cell, the leakage of the virus in the cell, I do not know)

To which component of the cell do the spines of the Coronavirus dock? (ACE2 receptors, Ribosomes, Cell membrane, Mitochondria, I do not know) Which protein is responsible for keeping RNA stable? (N-protein, Z-protein, S-protein, A-protein, I do not know) What is the function of the M-protein? (Form new virus particles, Driving the virus out of the cell, Protect the viral envelope, Facilitate the penetration of the virus, I do not know) Please take a look at the image below. "Illustration of 3D Model (Spektrum.de, 2019) with numbered regions". What is the name of the red thread (see number 2 figure)? (Viral RNA, Protective cover, Spike protein, Enzyme, I do not know) What are the orange thorns (number 3 in the figure) called? (Enzyme, M-protein, Spike protein, Viral RNA, I do not know)
Short-Term Evaluation: Knowledge gain (subj.), 6-point Likert Scale
The experiment gave me a better understanding of how the coronavirus works.
Short-Term Evaluation: Motivation, 6-point Likert Scale
Having completed this experiment, I am more motivated to learn about how the Coronavirus works.
Long-Term Evaluation: Knowledge (objective)
What happens during the last phase of the cycle of Coronavirus? (The Coronavirus emerges from the cell again and the healing phase begins, Many newly formed Coronaviruses emerge from the cell and infect other cells, The virus mutates in the cell and infects other cells, I do not know) How does the Coronavirus enter the cell? (The virus destroys the cell layer to infiltrate, The virus enters the cell through the ribosome, The virus docks onto ACE2 receptors of the cell to insert itself, I do not know) In the picture (WisdomVR documentation), you can see how… (The virus delivers its genetic information to the mitochondrion, The virus delivers its genetic information to the endoplasmic reticulum, The virus delivers its genetic information to the Golgi apparatus, I do not know) Which number in the figure ("Illustration of 3D Model (Spektrum.de, 2019) with numbered regions") represents the spike proteins? (7, 4, 3, I do not know) Which number in the figure ("Illustration of 3D Model (Spektrum.de, 2019) with numbered regions") represents the M-protein? (6 (yellow), 2 (red), 3 (orange), I do not know) What is the task of the E-protein? (Facilitates the penetration of the virus into the cell, Driving the virus out of the cell, Form new virus particles, I do not know) Endocytosis describes… (Copying RNA from the virus in the cell, The mutation of the virus in the cell, The docking of the virus to the receptors of the cells, I do not know) What is the function of viral RNA? (It is the blueprint that the virus uses to replicate itself, Protects the genetic cargo of the virus as it travels in the body, Keeps the virus stable, I do not know) The capsular envelope during the Coronavirus invasion is referred to as… (Cell layer, Inversion, Lipid bilayer, I do not know) The second phase of the Coronavirus cycle is (Endocytosis, Exocytosis, Duplication, I don't know)
Long-Term Evaluation: Knowledge gain (subj.), 6-point Likert Scale
I understand the mode of action of the Coronavirus.
Long-Term Evaluation: Motivation, 6-point Likert Scale
I researched more on how the Coronavirus works after this experiment was completed.

Table 6. Questionnaires.

References

Alhalabi, W. (2016). "Virtual reality systems enhance students' achievements in engineering education." *Behaviour & Information Technology*. ISSN: 0144-929X. DOI: 10.1080/0144929X.2016.1212931.

Ali, N., S. Ullah, A. Alam, and J. Rafique (2014). "3D interactive virtual chemistry laboratory for simulation of high school experiments." *Proceedings of Eurasia Graphics*, 1–6.

Ali, W. (2020). "Online and Remote Learning in Higher Education Institutes: A Necessity in Light of COVID-19 Pandemic." *Higher Education Studies* 10 (3), 16–25. ISSN: 1925-4741. URL: https://eric.ed.gov/?id=ej1259642.

Allcoat, D. and A. von Mühlenen (2018). "Learning in virtual reality: Effects on performance, emotion and engagement." *Research in Learning Technology* 26 (0). DOI: 10.25304/rlt.v26.2140. URL: http://journal.alt.ac.uk/index.php/rlt/article/view/2140.

Anderson, L. W. and D. R. Krathwohl (2021). "A taxonomy for learning, teaching, and assessing: a revision of Bloom's taxonomy of educational objectives." URL: http://dspace.vnbrims.org:13000/xmlui/handle/123456789/4570.

Andrews, F. M. (1984). "Construct Validity and Error Components of Survey Measures: A Structural Modeling Approach." *Public Opinion Quarterly* 48 (2), 409–442. ISSN: 0033-362X. DOI: 10.1086/268840.

Ankomah, P. and P. Vangorp (2018). "Virtual Reality: A literature review and metrics based classification." *Computer Graphics & Visual Computing (CGVC) 2018*, 173–181. DOI: 10.2312/cgvc.20181222.

Banas, E. J. and W. F. Emory (1998). "History and issues of distance learning." *Public Administration Quarterly*, 365–383.

Barfield, W. and C. Hendrix (1995). "The effect of update rate on the sense of presence within virtual environments." *Virtual Reality* 1 (1), 3–15. ISSN: 1434-9957. DOI: 10.1007/BF02009709. URL: https://idp.springer.com/authorize/casa?redirect_uri=https://link.springer.com/article/10.1007/bf02009709&casa_token=2qyuslvk8jsaaaaa:ldlwxqyc0lbfcfzmnwxirbomewzau6byinx3-sr2fzjsme_nwnhve4tuto9ku-bvuiomv_ek5ztoaz5ecq.

Basak, S. K., M. Wotto, and P. Belanger (2018). "E-learning, M-learning and D-learning: Conceptual definition and comparative analysis." *E-Learning and Digital Media* 15 (4), 191–216. DOI: 10.1177/2042753018785180.

Bencheva, N. (2010). "Learning styles and e-learning face-to-face to the traditional learning." *t* 49 (3.2), 63–67.

Bowman, D. A. and R. P. McMahan (2007). "Virtual reality: how much immersion is enough?" *Computer* 40 (7), 36–43. ISSN: 0018-9162.

Brooks, F. P. (1999). "What's real about virtual reality?" *IEEE Computer Graphics and Applications* 19 (6), 16–27. ISSN: 02721716. DOI: 10.1109/38.799723.

Buckingham, D. (2007). "Media education goes digital: an introduction." *Learning, Media and Technology* 32 (2), 111–119. ISSN: 1743-9884. DOI: 10.1080/17439880701343006.

Choi, D. H., A. Dailey-Hebert, and J. S. Estes, eds. (2021). *Current and Prospective Applications of Virtual Reality in Higher Education*. IGI Global. ISBN: 9781799849605. DOI: 10.4018/978-1-7998-4960-5.

Cohen, P., S. G. West, and L. S. Aiken (2014). *Applied multiple regression/correlation analysis for the behavioral sciences*. Psychology Press.

Converse, J. M. and S. Presser (1986). *Survey questions: Handcrafting the standardized questionnaire*. Vol. 63. CA: Sage.

Da Costa, L. A. L. and L. P. Nedel (2017). "An Immersive Visualization Study on Molecules Manipulation." In: *2017 19th Symposium on Virtual and Augmented Reality (SVR)*. IEEE, pp. 169–177. DOI: 10.1109/svr.2017.30.

Ebbinghaus, H. (1885). *Über das Gedächtnis: Untersuchungen zur experimentellen Psychologie*. Duncker & Humblot.

Efron, B. and R. J. Tibshirani (1994). *An introduction to the bootstrap*. CRC press.

Fischer, L., J. Christiansen, B. Glaunsinger, M. Fischetti, Hays, Veronica Falconieri, and A. Schadwinkel (2021-27-02). *Wie das Coronavirus angreift*. URL: https://www.spektrum.de/wissen/animation-zu-covid-19-wie-das-coronavirus-angreift/1790243 (visited on 11/02/2022).

Fogarty, J., J. McCormick, and S. El-Tawil (2018). "Improving Student Understanding of Complex Spatial Arrangements with Virtual Reality." *Journal of Professional Issues in Engineering Education and Practice* 144 (2), 04017013. DOI: 10.1061/(ASCE)EI.1943-5541.0000349.

Freina, L. and M. Ott (2015). "A Literature Review on Immersive Virtual Reality in Education: State Of The Art and Perspectives." In: *The international scientific conference elearning and software for education*. Vol. 1, pp. 10–1007. URL: https://www.researchgate.net/publication/280566372_A_Literature_Review_on_Immersive_Virtual_Reality_in_Education_State_Of_The_Art_and_Perspectives.

Gros, B. (2007). "Digital games in education: The design of games-based learning environments." *Journal of Research on Technology in Education* 40 (1), 23–38.

Hamilton, D., J. McKechnie, E. Edgerton, and C. Wilson (2021). "Immersive virtual reality as a pedagogical tool in education: a systematic literature review of quantitative learning outcomes and experimental design." *Journal of Computers in Education* 8 (1), 1–32. ISSN: 2197-9995. DOI: 10.1007/s40692-020-00169-2. URL: https://link.springer.com/article/10.1007/s40692-020-00169-2.

Harrington, C. M., D. O. Kavanagh, J. F. Quinlan, D. Ryan, P. Dicker, D. O'Keeffe, O. Traynor, and S. Tierney (2018). "Development and evaluation of a trauma decision-making simulator in Oculus virtual reality." *American Journal of Surgery* 215 (1), 42–47. DOI: 10.1016/j.amjsurg.2017.02.011.

Harrington, C. M., D. O. Kavanagh, G. Wright Ballester, A. Wright Ballester, P. Dicker, O. Traynor, A. Hill, and S. Tierney (2018). "360° Operative Videos: A Randomised Cross-Over Study Evaluating Attentiveness and Information Retention." *Journal of Surgical Education* 75 (4), 993–1000. ISSN: 1931-7204. DOI: 10.1016/j.jsurg.2017.10.010.

Hasselhorn, M. and A. Gold (2013). *Pädagogische Psychologie: Erfolgreiches Lernen und Lehren*. 3., vollständig überarbeitete und erweiterte Auflage. Kohlhammer Standards Psychologie. Stuttgart: Verlag W. Kohlhammer. ISBN: 978-3-17-022462-9.

Hassenzahl, M. (2018). *A personal journey through user experience*. URL: https://uxpajournal.org/wp-content/uploads/sites/7/pdf/jus_hassenzahl_august2018.pdf.

Hedberg, J. and S. Alexander (1994). "Virtual Reality in Education: Defining Researchable Issues." *Educational Media International* 31 (4), 214–220. ISSN: 1469-5790. DOI: 10.1080/0952398940310402.

Hoffmann, G. and J. Pfeiffer (2021). "Gameful Learning for a More Sustainable World: Measuring the Effect of Design Elements on Long-Term Learning Outcomes in Correct Waste Sorting." *Business & Information Systems Engineering*, 1–24. ISSN: 2363-7005. DOI: 10.1007/s12599-021-00731-x. URL: https://link.springer.com/article/10.1007/s12599-021-00731-x.

Huang, H.-M. and S.-S. Liaw (2011). "Applying Situated Learning in a Virtual Reality System to Enhance Learning Motivation." *International Journal of Information and Education Technology* 1 (4), 298–302. ISSN: 2010-3689. DOI: 10.7763/ijiet.2011.v1.48.

Huang, H.-M., U. Rauch, and S.-S. Liaw (2010). "Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach." *Computers & Education* 55 (3), 1171–1182. ISSN: 0360-1315. DOI: 10.1016/j.compedu.2010.05.014. URL: https://www.sciencedirect.com/science/article/pii/s0360131510001466.

K. Babu, S., S. Krishna, U. R., and R. R. Bhavani (2018). "Virtual Reality Learning Environments for Vocational Education: A Comparison Study with Conventional Instructional Media on Knowledge Retention." In: *2018 IEEE 18th International Conference on Advanced Learning Technologies (ICALT)*. IEEE. DOI: 10.1109/icalt.2018.00094.

Kamińska, D., T. Sapiński, S. Wiak, T. Tikk, R. Haamer, E. Avots, A. Helmi, C. Ozcinar, and G. Anbarjafari (2019). "Virtual Reality and Its Applications in Education: Survey." *Information* 10 (10), 318. DOI: 10.3390/info10100318.

Katz, D. (1942). "Do Interviewers Bias Poll Results?" *Public Opinion Quarterly* 6 (2), 248–268. ISSN: 0033-362X. DOI: 10.1086/265548.

Kavanagh, S., A. Luxton-Reilly, B. Wuensche, and B. Plimmer (2017). "A systematic review of Virtual Reality in education." *Themes in Science and Technology Education* 10 (2), 85–119. URL: https://www.learntechlib.org/p/182115/.

Keengwe, J. and G. Onchwari (2011). "Fostering meaningful student learning through constructivist pedagogy and technology integration." *International Journal of Information and Communication Technology Education (IJICTE)* 7 (4), 1–10.

Keith, N. and M. Frese (2008). "Effectiveness of error management training: a meta-analysis." *The Journal of applied psychology* 93 (1), 59–69. ISSN: 0021-9010. DOI: 10.1037/0021-9010.93.1.59.

Kraiger, K., J. K. Ford, and E. Salas (1993). "Application of cognitive, skill-based, and affective theories of learning outcomes to new methods of training evaluation." *Journal of Applied Psychology* 78 (2), 311–328. ISSN: 0021-9010. DOI: 10.1037/0021-9010.78.2.311.

Lawrence, J. E. and U. A. Tar (2018). "Factors that influence teachers' adoption and integration of ICT in teaching/learning process." *Educational Media International* 55 (1), 79–105. ISSN: 1469-5790. DOI: 10.1080/09523987.2018.1439712.

Le, Q. T., A. Pedro, and C. S. Park (2015). "A social virtual reality based construction safety education system for experiential learning." *Journal of Intelligent & Robotic Systems* 79 (3), 487–506.

Lungu, A. J., W. Swinkels, L. Claesen, P. Tu, J. Egger, and C. Xiaojun (2020). "A review on the applications of virtual reality, augmented reality and mixed reality in surgical simulation: an extension to different kinds of surgery." *Expert Review of Medical Devices*, 47–62. DOI: 10.1080/17434440.2021.1860750.

Makransky, G., T. S. Terkildsen, and R. E. Mayer (2019). "Adding immersive virtual reality to a science lab simulation causes more presence but less learning." *Learning and Instruction* 60, 225–236. ISSN: 0959-4752. DOI: 10.1016/j.learninstruc.2017.12.007.

Mantovani, F. (2001). "VR Learning : Potential and Challenges for the Use of 3 D Environments in Education and Training." *R. Guiseppe, & C. Galimberti, Towards cyberpsychology: Mind, cognitions and society in the internet age*, 207–226. URL: https://www.semanticscholar.org/paper/VR-Learning-%3A-Potential-and-Challenges-for-the-Use-Mantovani/c7f8d19850f4a88655fe81caea89912dcad66241.

— (2003). "VR learning: Potential and challenges for the use of 3D environments in education and training."

Mayer, R. E. (2002). "Multimedia learning." In: *Psychology of learning and motivation*. Vol. 41. Elsevier, pp. 85–139.

Mayer, R. E. and R. Moreno (1998). "A cognitive theory of multimedia learning: Implications for design principles." *Journal of Educational Psychology* 91 (2), 358–368. ISSN: 1939-2176.

McCloy, R. and R. Stone (2001). "Science, medicine, and the future: Virtual reality in surgery." *BMJ* 323 (7318), 912–915. ISSN: 0959-8138. DOI: 10.1136/bmj.323.7318.912. URL: https://www.bmj.com/content/323/7318/912?lookuptype=volpage%253feaf.

Menold, N. and K. Bogner (2015). "Gestaltung von Ratingskalen in Fragebögen." *Mannheim, GESIS–Leibniz-Institut für Sozialwissenschaften (SDM Survey Guidelines). DOI* 10.

Molina-Carmona, R., M. L. Pertegal-Felices, A. Jimeno-Morenilla, and H. Mora-Mora (2018). "Virtual Reality Learning Activities for Multimedia Students to Enhance Spatial Ability." *Sustainability* 10 (4), 1074. ISSN: 2071-1050. DOI: 10.3390/su10041074. URL: https://www.mdpi.com/279130.

Murre, J. M. J. and J. Dros (2015). "Replication and Analysis of Ebbinghaus' Forgetting Curve." *PloS one* 10 (7), e0120644. DOI: 10.1371/journal.pone.0120644. URL: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0120644.

Pan, X. and A. F. d. C. Hamilton (2018). "Why and how to use virtual reality to study human social interaction: The challenges of exploring a new research landscape." *British journal of psychology (London, England : 1953)* 109 (3), 395–417. DOI: 10.1111/bjop.12290.

Pan, Z., A. D. Cheok, H. Yang, J. Zhu, and J. Shi (2006). "Virtual reality and mixed reality for virtual learning environments." *Computers & Graphics* 30 (1), 20–28. ISSN: 00978493. DOI: 10.1016/j.cag.2005.10.004.

Pantelidis, V. S. (1996). "Suggestions on when to use and when not to use virtual reality in education." *VR in the Schools* 2 (1), 18.

— (2010). "Reasons to Use Virtual Reality in Education and Training Courses and a Model to Determine When to Use Virtual Reality." *Themes in Science and Technology Education* 2 (1-2), 59–70. URL: http://earthlab.uoi.gr/ojs/theste/index.php/theste/article/view/22.

Papanis, E. (2005). "Traditional Teaching versus e-learning." *Experimental Approach, Statistical Review* 1 (1), 19–35.

Parmar, D., J. Bertrand, S. V. Babu, K. Madathil, M. Zelaya, T. Wang, J. Wagner, A. K. Gramopadhye, and K. Frady (2016). "A comparative evaluation of viewing metaphors on psychophysical skills education in an interactive virtual environment." *Virtual Reality* 20 (3), 141–157. ISSN: 1434-9957. DOI: 10.1007/s10055-016-0287-7. URL: https://idp.springer.com/authorize/casa?redirect_uri=https://link.springer.com/article/10.1007/s10055-016-0287-7&casa_token=6006h242ajgaaaaa:wxtdxf_btpbadv-dru65mhibd0ncqbof_quylfv5sl3ls74qtssgnw1jm23bdljibp0iizcdgpspardh.

Pek, J., O. Wong, and A. Wong (2018). "How to address non-normality: A taxonomy of approaches, reviewed, and illustrated." *Frontiers in Psychology* 9, 2104. ISSN: 1664-1078.

Philippe, S., A. D. Souchet, P. Lameras, P. Petridis, J. Caporal, G. Coldeboeuf, and H. Duzan (2020). "Multimodal teaching, learning and training in virtual reality: a review and case study." *Virtual Reality & Intelligent Hardware* 2 (5), 421–442. ISSN: 20965796. DOI: 10.1016/j.vrih.2020.07.008. URL: https://www.sciencedirect.com/science/article/pii/S2096579620300711.

Polites and Karahanna (2012). "Shackled to the Status Quo: The Inhibiting Effects of Incumbent System Habit, Switching Costs, and Inertia on New System Acceptance." *MIS Quarterly* 36 (1), 21. ISSN: 02767783. DOI: 10.2307/41410404.

Prenzel, M., A. Kristen, P. Dengler, R. Ettle, and T. Beer (1996). "Selbstbestimmt motiviertes und interessiertes Lernen in der kaufmännischen Erstausbildung." *Zeitschrift für Berufsund Wirtschaftspädagogik*, 108–127.

Radianti, J., T. A. Majchrzak, J. Fromm, and I. Wohlgenannt (2020). "A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda." *Computers & Education* 147, 103778. ISSN: 0360-1315. DOI: 10.1016/j.compedu.2019.103778. URL: https://www.sciencedirect.com/science/article/pii/S0360131519303276.

Rauschnabel, P. A., R. Felix, C. Hinsch, H. Shahab, and F. Alt (2022). "What is XR? Towards a Framework for Augmented and Virtual Reality." *Computers in Human Behavior* 133, 107289. ISSN: 07475632. DOI: 10.1016/j.chb.2022.107289. URL: https://www.sciencedirect.com/science/article/pii/S074756322200111X.

Sankaranarayanan, G., L. Wooley, D. Hogg, D. Dorozhkin, J. Olasky, S. Chauhan, J. W. Fleshman, S. De, D. Scott, and D. B. Jones (2018). "Immersive virtual reality-based training improves response in a simulated operating room fire scenario." *Surgical Endoscopy* 32 (8), 3439–3449. ISSN: 1432-2218. DOI: 10.1007/s00464-018-6063-x. URL: https://idp.springer.com/authorize/casa?redirect_uri=https://link.springer.com/article/10.1007/s00464-018-6063-x&casa_token=xrh5wknujj8aaaaa:o2egnqe8ap_cjon1jn_rhlgvucpa5gelpdcuenm_jsxof5ncav8eudqicsl9zptejndkw5xqvb9zn0rn.

Sattar, M. U., S. Palaniappan, A. Lokman, A. Hassan, N. Shah, and Z. Riaz (2019). "Effects of Virtual Reality training on medical students' learning motivation and competency." *Pakistan journal of*

medical sciences 35 (3), 852–857. ISSN: 1682-024X. DOI: 10.12669/pjms.35.3.44. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6572943/.

Schmidt, R. A. and R. A. Bjork (1992). "New Conceptualizations of Practice: Common Principles in Three Paradigms Suggest New Concepts for Training." *Psychological Science* 3 (4), 207–218. ISSN: 0956-7976. DOI: 10.1111/j.1467-9280.1992.tb00029.x.

Schultze, U. (2010). "Embodiment and presence in virtual worlds: a review." *Journal of Information Technology* 25 (4), 434–449.

Servos, P. (2000). "Distance estimation in the visual and visuomotor systems." *Experimental brain research* 130 (1), 35–47. ISSN: 0014-4819. DOI: 10.1007/s002210050004. URL: https://link.springer.com/article/10.1007/s002210050004.

Shahab, M. H., E. Ghazali, and M. Mohtar (2021). "The role of elaboration likelihood model in consumer behaviour research and its extension to new technologies: A review and future research agenda." *International Journal of Consumer Studies* 45 (4), 664–689. ISSN: 1470-6423. DOI: 10.1111/ijcs.12658.

Slater, M., V. Linakis, M. Usoh, and R. Kooper (1996). "Immersion, presence and performance in virtual environments: An experiment with tri-dimensional chess." In: *Proceedings of the ACM Symposium on Virtual Reality Software and Technology: VRST'96, Hong Kong, July 1 - 4, 1996*. New York: Ass. of Computing Machinery, pp. 163–172. ISBN: 0897918258. DOI: 10.1145/3304181.3304216.

Smith, S. J., S. L. Farra, D. L. Ulrich, E. Hodgson, S. Nicely, and A. Mickle (2018). "Effectiveness of Two Varying Levels of Virtual Reality Simulation." *Nursing Education Perspectives* 39 (6), E10. ISSN: 1536-5026. DOI: 10.1097/01.NEP.0000000000000369. URL: https://journals.lww.com/neponline/fulltext/2018/11000/effectiveness_of_two_varying_levels_of_virtual.21.aspx.

Somayeh, M., M. Dehghani, F. Mozaffari, S. M. Ghasemnegad, H. Hakimi, and B. Samaneh (2016). "The effectiveness of E-learning in learning: A review of the literature." *International journal of medical research & health sciences* 5 (2), 86–91.

Steuer, J. (1992). "Defining Virtual Reality: Dimensions Determining Telepresence." *Journal of Communication* 42 (4), 73–93. ISSN: 00219916. DOI: 10.1111/j.1460-2466.1992.tb00812.x.

Tredinnick, R., J. Vanderheiden, C. Suplinski, and J. Madsen (2014). "CAVE visualization of the IceCube neutrino detector." In: *2014 IEEE Virtual Reality (VR)*. IEEE, pp. 117–118. DOI: 10.1109/vr.2014.6802079.

Webster, R. (2016). "Declarative knowledge acquisition in immersive virtual learning environments." *Interactive Learning Environments* 24 (6), 1319–1333. ISSN: 1049-4820. DOI: 10.1080/10494820.2014.994533.

Wu, B., X. Yu, and X. Gu (2020). "Effectiveness of immersive virtual reality using head-mounted displays on learning performance: A meta-analysis." *British Journal of Educational Technology* 51 (6), 1991–2005. ISSN: 0007-1013. DOI: 10.1111/bjet.13023.

Xi, N. and J. Hamari (2021). "Shopping in virtual reality: A literature review and future agenda." *Journal of Business Research* 134, 37–58. ISSN: 01482963. DOI: 10.1016/j.jbusres.2021.04.075.

Yoganathan, S., D. A. Finch, E. Parkin, and J. Pollard (2018). "360° virtual reality video for the acquisition of knot tying skills: A randomised controlled trial." *International Journal of Surgery* 54, 24–27. ISSN: 1743-9191. DOI: 10.1016/j.ijsu.2018.04.002.

Yost, G., A. Loften, and A. Murdock (2021). "Inside COVID19." In: *ACM SIGGRAPH 2021 VR Theater*. New York, NY, USA: ACM. DOI: 10.1145/3446367.3451162.

Zavalani, O. and A. Spahiu (2012). "Use curiosity for virtual reality "as a hook" in the engineering education." In: *2012 15th International Conference on Interactive Collaborative Learning (ICL)*, pp. 1–4.

Zender, R., M. Weise, M. von der Heyde, and H. Söbke (2018). "Lehren und Lernen mit VR und AR–Was wird erwartet? Was funktioniert." In: *Proceedings of DeLFI Workshops*. Vol. 16.

Let Others Play in your Sandbox: Virtual Reality-based Experiments on Shopping Behavior

Tobias Stejskal[a], Thies Pfeiffer[c], Jella Pfeiffer[b]

[a]*Justus Liebig University Giessen, Licher Straße 74, Gießen, 35394, Germany*
[b]*Institute of Business Administration, University of Stuttgart, Keplerstraße 17, Stuttgart, 70174, Germany*
[c]*Institute for Human-Computer Interaction, University of Applied Sciences Emden/Leer, Constantiaplatz 4, Emden, 26723, Germany*

Abstract

Virtual Reality (VR) seeks to enable users to experience and interact as they would in the physical world. In this paper, we scrutinize whether shopping behavior in VR environments mirrors that of equivalent physical, real-world situations. Through an analysis of interaction data gathered in an experiment with 100 participants in comparable VR and non-VR shopping settings, we aim to analyze the similarities in interaction and discern general patterns that manifest in both worlds. We conclude that purchase decisions and the shopping process are very similar for low-involvement, low-cost product choices. However, the underlying interactions with products are different.

Keywords: Virtual Reality, Shopping, Product Interaction, Head-mounted Displays, Experiment Environment

The authors report there are no competing interests to declare.

The participants of this study did not give written consent for their data to be shared publicly, so due to the sensitive nature of the research supporting data is not available.

Email address: tobias.stejskal@wirtschaft.uni-giessen.de (Tobias Stejskal)
URL: https://www.linkedin.com/in/thiespfeiffer/ (Thies Pfeiffer), https://www.linkedin.com/in/jella-pfeiffer-a95505232/ (Jella Pfeiffer)

Participants gave informed written consent to be part of the study. No ethics approval was required.

Virtual Reality (VR) applications have been developed for various fields such as gaming[1], education[2, 3], and engineering[4]. One domain that could significantly impact the landscape as VR platforms continue to commercialize is the realm of VR shopping applications[5, 6]. However, to construct successful immersive applications, a comprehensive understanding of human-computer interaction and further advancements of VR interface technologies are imperative.

But even if VR shopping situations still belong to the unknown future, in the realm of experimental design, the prospect of a seamlessly automated data collection throughout a laboratory experiment has sparked interest in the potential applications of VR [7, 8]. With the rise of affordable VR head-mounted displays (HMD) and accessible design software, conducting experiments in VR becomes viable [9, 10, 11, 12]. Conducting experiments in VR offers two advantages: high control and unprecedented possibilities for collecting participant data [2, 13]. For instance, to increase the level of control, external confounding factors can be mitigated compared to real-world scenarios, such as the influence of others' experiences in the scene or the impact of surrounding light and sound. Additionally, the experimental environment can be automatically configured for each participant, applying adjustments such as switching easily between treatments or a randomization of stimuli in the environment. Furthermore, virtually any data about the virtual environment can be automatically recorded and evaluated in great detail, given that all events take place within the computer simulation. But experiments in VR could also introduce uncertainty in experimental methodologies [8]. This concerns cost and practically, but also validity, which is the focus of the presented research.

One research field, where experiments in VR instead of physical environments has been gained particular interest, is consumer behavior research, particularly shopping research [5, 13, 14]. However, the question arises as to the validity of the findings obtained using VR as experimental environment. Therefore, we address the research question of whether shopping behavior observed in VR is comparable to real-world scenarios. Addressing this is central to validating the efficacy of utilizing VR in studying and understanding shopping behavior. Furthermore, understanding human-computer interaction in

VR shopping scenarios might become an important aspect for marketers of future real-world VR shopping applications.

In our experiment, we collected data from 100 participants in front of product shelves filled with mueslis. In a between-subject design, we showed two separate but identical muesli shelves in VR and physical reality and analyzed the participants' product choices and product interaction data. We take into account both overarching data like purchasing decisions as well as low-level data like the grabbing and releasing of each product. We would have expected VR users to lean towards the hedonic perspective of a shopping experience [15], instead they appear to be more efficient, which is in line with Hepperle and Wölfel [8]. More specifically, our task setup of shopping for muesli in a VR store corresponds to the utilitarian fit, as it has a specific goal with low arousal [16]. To enhance external validity, we incentivized the experiment by concluding it with actual purchases by the participants.

The results of our research contribute significantly in two main areas: Firstly, they assist in assessing the sustained validity of knowledge derived from real-world experiences to virtual reality, specifically in the context of physical brick-and-mortar stores. This holds significance for researchers interested in studying real-world shopping scenarios in a more controlled environment, enhancing factors such as validity and reproducibility. Additionally, the abundance of sensor data available enables a detailed examination of user behavior, facilitating a finer-grained analysis. Secondly, it helps identifying challenges and innovations for shopping experiences in virtual reality that come from observed differences in user behavior in VR compared to what is known. This, in turn, will help providers of future VR retail environments tailoring the applications to the users' needs.

1. Prior Works

VR technology has undergone significant improvements, marked by advancements in the quality of virtual experiences [17, 18]. This progress can be at least partially attributed to the continuous evolution of HMDs [19], which currently serve as the central enabling technology for consumer VR [20]. VR also benefits from further developments in computer graphics, the 3D game engines used and advances in motion tracking, such as room-scale tracking. The general accessibility of VR hardware has increased due to ongoing advancements, making it more affordable for a broader user base [21]. As a

result, VR technology is maturing rapidly, indicating the likelihood of immersive store fronts becoming an equitable platform for sales [22, 5].

In contemporary research, the focus has shifted from isolated VR shopping experiences to a broader examination within the context of the technology-agnostic concept of the Metaverse [23, 11, 12]. VR shopping has recently been compared to eCommerce [13], where shoppers in VR were found to be less sensitive to prices. VR technology also slightly encouraged variety-seeking but had no effect on how satisfied shoppers were with their purchase. Similar results were found in the study by Pizzi et al. [24] that showed product perception and product choice to be comparable.

While eCommerce continues to grow, it has not completely displaced retail offerings. Importantly, physically interacting with and holding a product is a significant aspect of the product evaluation process [25, 26, 27]. According to [25], consumers harbor an instrumental need for touch, due to need to perform goal-oriented evaluations (i.e., to better evaluate product properties) which often shape the final product assessment [28]. Interacting with the product also has the positive impact of a favorable attitude [25]. For our research it is important to note, that this effect also extends into virtual environments, where touch is primarily a product of imagination [25]. In general, the act of touching a product is emphasized as being even more crucial than visual information in influencing consumer decisions [29, 30]. Crucially, VR has the potential to provide many of the same benefits that eCommerce offers, while incorporating characteristics of retail stores.

Users rely on input devices to translate their actions into the virtual environment [31, 32, 33]. While tracking position and posture of human hands is possible, current systems lack haptic feedback, which limits the engagement of interactions. Currently available controllers use basic haptic feedback elements via rumble/vibration to approach a natural feeling feedback within simulated worlds [31, 32]. The better the controllers convey the impression of touch [32], as well as a direct transfer of the intended interaction into a simulated one, the more precisely users can act [31, 32, 33] and the more present they are [32].

To sum up, existing literature has focused on comparing shopping in eCommerce with shopping in VR environments. We continue this line of research but compare VR to shopping in front of physical shelves as common in brick-and-mortar stores. Furthermore, research has shown that product interactions are an important part of shopping behavior. Our analysis therefore not only includes high-level behavior like the final choices made but also

analyses of the detailed handling of products.

2. Method

2.1. Experiment Design

Our research group collected observations of purchase decisions of mueslis in VR and real-life scenarios in a controlled environment at a European university's laboratory. Each participant received an initial endowment of 14€ and was informed, that one of their purchases would actually take place. The price of their muesli box was then subtracted from their initial endowment and the actual product was handed over at the end of the experiment, together with the rest of their payment.

None of the participants had prior experience with VR. To compare shopping behavior between the two scenarios, we conducted a between-subjects laboratory experiment. The participants were tasked with deciding on several products to purchase, either in front of our real shopping shelf, or in a highly immersive VR copy of the real shelf whilst wearing the HTC Vive HMD. It was ensured that the two shelves were as similar as possible. We will refer to our two groups in the following as the Real and the VR group. To complete a task, participants had to place the chosen boxes in a nearby shopping cart.

Both groups were instructed and performed the first eight purchase tasks in VR. This was necessary because the data set was also used for a conjoint-based choice analysis that is not part of this paper [13]. The conjoint-based approach is used to measure consumers' utility values for products and prices and requires the same consumer to make several product choices sequentially. For the purpose of this paper of comparing the shopping behavior in front of physical shelves and VR shelves, we therefore split the participants randomly in two groups after the conjoint-measurement was finished , which were tasks 9 and 10. Thus, task 9 and 10 are the basis for our data analysis, but for better readability we will refer to them as Task 1 and 2 going forward. We picked muesli as a product category, because it is a popular product in Germany and we could ensure that all participants were interested in them. In addition to that, muesli boxes can be presented efficiently in 3D and require handling to assess all information available on the packages' front, back and sides. All tasks were to purchase muesli, as a low involvement, habitually purchased product category.

The experiment included 40 products, of which 24 were selected for each of the two tasks and arranged in a 4x6 matrix on the shelf, both in VR and the Real one (see Figures 1 and 2). Products were grouped by brand placed in a way that avoids centrality effects [34]. For each of the two tasks, participants in both treatments (VR and Real) experienced identical product arrangements on the shelf. The participants' task was to pick one of the products from each of the two shelves according to their own preferences and put them in the shopping cart.

The products themselves can be classified regarding two main categories according to sugar content and brand. Six of the products specifically mentioned containing less sugar than a comparable product, which we will refer to as low-sugar. These products had a corresponding text notice prominently placed on the front. In addition, a lower sugar content is stated in the nutritional information. The packaging design was also slightly different in color from the comparable full-sugar product. Secondly, the products can be linked to three different product categories by brand association. Mueslis were available from the brands Vitalis, Koelln and discounter's house brand, with the first two being widely regarded as being of good quality. However, all of them are well known to the participants as not to influence the decision making process.

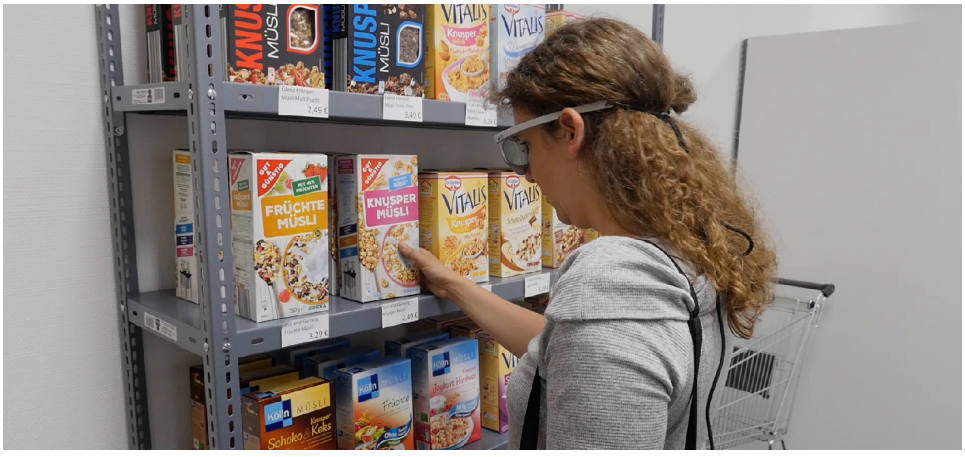

Figure 1: Experiment setup of the real shopping situation in front of a shelf. Participants wore mobile eye-tracking glasses recording their actions with a front-facing camera.

Figure 2: Experiment setup of the virtual shopping situation with an exact replication of the real shelf. Participants used an HTC Vive HMD with controllers to interact with the products.

2.2. Technical Setup

The VR environment was built to incorporate head and controller tracking. It was implemented with the Unity 5.5.3f1 game engine. Participants were situated in a plain virtual room with a shelf of product packages and a shopping cart. They were observed by staff while using VR to avoid injuries. We used an HTC Vive HMD with a dual display of 1080×1200 pixels resolution each and HTC hand-held controllers. In contrast to Speicher et al. [35], our experiment did not introduce extended interaction capabilities beyond what is possible in reality.

3. Gathering Data

In order to compare the shopping behavior between the real and virtual environment, we had to restrict the data being gathered to information available in both. While VR is capable of tracking an extensive variety of data points at very tight time intervals, the same is not true for a real experiment setup without tremendous efforts.

Product interactions, however, in the form of the actions grabbing, holding, putting back, and buying, are central to a physical shopping experi-

ence [35]. Participants in the Real group wore the SMI Eye Tracking Glasses 2 Wireless. This device is capable of binocular eye tracking (120 Hz) and wireless video and audio transmission of the wearers perspective. While interactions could be directly recorded in VR, in the Real group they were transcribed from the captured video feed afterwards. However, we encountered data quality issues when trying to replicate the results of SMIs proprietary algorithm for a given gaze input. Therefore we had to discard the eye tracking data, as results would've been distorted by the difference in algorithms between the VR and Real group. This resulted in a data set that includes two sets of entries per participant that include: The participant's identification number, the affected products identification number, the hand interacting, was the product grabbed/released/bought, the task, the group and how much time had passed in the task.

For the identification of interactions in the Real group, an annotation process with human coders was necessary. Our original intent was to not only compare product interaction data (with the users' hands) but also eye-tracking data. Therefore the annotation process was rigorous and conducted by a group of four students. The start and end times of product interactions had to be annotated, as well as the exact product for the mobile eye-tracking fixations. First, rules and guidelines on how to annotate in specific situations were discussed. Then, all annotators conducted the coding for one example video. Following this, the annotations were compared, divergences discussed, and the annotation rules were updated. There was almost no ambiguity for the interaction annotations but slightly more for exact positions of the eye-tracking fixations. Subsequently, seven different videos were annotated for test purposes, of which six videos were annotated by a pair of two annotators and the remaining video was annotated by all four annotators. After this procedure, Krippendorff's alpha was computed which was with > 0.8 acceptable. Finally, the remaining videos were distributed among the annotators.

3.1. Data Filtering/Cleaning

When first reviewing the data it became apparent, that a small number of VR product interactions were involuntary in nature. In order to consider only intentional interactions in our evaluation, an average reaction time of $200ms$ was chosen as the lower threshold [36]. This removed four product interactions from the VR group only, and none from the group shopping at the real shelves.

4. Results and Discussion

To analyze our data set, we start with the question of whether the purchasing decisions of the two groups are comparable. We then look at whether the product evaluation process that led to this decision is identical. Finally, we look at the individual interactions in detail in order to understand whether the underlying actions in the shopping environment are comparable.

4.1. Descriptive Statistics

The descriptive statistics for both groups can be found in Table 1. As the participants were recruited from a pool of students, the average age is in the early 20s, with 22.1 for the Real group and 23.02 for VR respectively. Both groups had more participants that self-reported as male, rather than female with 64% and 67%. No participants indicated any 'other' gender. Less than half of participants used glasses to correct their sight with 31.1% in the Real group and 43.6% in the VR group. In order to recognize possible effects of enthusiasm for new technology, we also asked respondents whether they would identify themselves as "early adopters", with 53% and 47% indicating that it applied to them.

Table 1: Descriptive Statistics

	Real	VR
Participants	45	55
Age	22.1 (2.03)	23.02 (3.11)
Sex	64.4% male	67.3% male
Glasses	31.1%	43.6%
Technology enthusiast	53.3%	47.3%

Overall the two groups have similar age, gender distribution, need for sight correction and affinity for new technology with the KS test reporting $p > 0.76$ for all categories.

4.2. Purchasing Decision

4.2.1. Price

We will start our analysis with one important aspect of the choice itself: the price of the chosen muesli. The VR group chose mueslis with an average price of 2.08€ (std=0.46) in task 1, 2.14€ (std=0.7) in task 2, and 2.11€

(std=0.5) on average over both tasks. The Real group chose mueslis for 1.97€ (std=0.39) in task 1, 2.21€ (std=0.77) in task 2, and 2.09€ (std=0.61) averaged over both tasks.

In order to establish whether these differences are statistically significant, we rely on non-parametric testing because of the Kolmogorov-Smirnov (KS) test reporting non-normal distributions. With the KS test reporting $p = 1$, no significant difference can be found with respect to the price of the chosen products when averaged over both tasks (see also Table 2).

Table 2: Purchase Prices

	Group	Mean in €	Std. Dev.
Task 1	VR	2.08	0.46
	Real	1.97	0.39
Task 2	VR	2.14	0.7
	Real	2.21	0.77
Combined	VR	2.11	0.59
	Real	2.09	0.61

We can further break down purchasing decisions by sugar content and brand (see Table 3). As the KS test is not suitable for discrete distributions, such as our categories, we have opted to rely on the chi-square test instead. For the share of the brands of total sales, the chi-square test shows that these are statistically not different with $p = 0.91$. On the other hand, comparing the choice of sugar content yields $p < 0.01$. This shows that while participants choose similar brands across both environments, they opted for more healthier, sugar-reduced muesli in the virtual environment.

Table 3: Purchased Categories

	VR	Real
Koelln	41.82%	43.82%
Vitalis	47.27%	46.07%
Discounter	10.9%	10.11%
Sugar-reduced	21.82%	12.36%

4.2.2. Time until Purchase

We will now look at the time spent before making a purchase in each task, i.e. the length of the decision situation. For a clearer depiction of the distribution, we utilize a split violin plot in Figure 3. Here the X-axis represents the time elapsed since the initial moment a participant begins the respective task and with that the decision making process. Time is measured in seconds, starting from zero (0 s) and extending to the maximum duration observed for a purchase decision within the study. The distribution shows slightly different shapes, with the VR group spending less time on average. In fact, the mean time spent shopping in front of the real shelves is with 58.8s (std=24.6) significantly larger than the mean time in VR (46.1s (std=24.6), KS-test with $p < 0.001$). Because there is a visible outlier for the Real group, shopping for 242.9s in comparison to the longest shopping duration in VR with 144.5s, we did some robustness checks. First, we manually checked all of the participant's data again but could not find any inaccuracies or possible errors with the procedure that would justify the exclusion of this observation. We also compared the means when removing this extremely long shopper from the real scenario, leading to a slightly decreased mean time until purchase of 56.7s (std=23.8), instead of 58.8s. Yet, the KS test still shows a significant difference with this slightly decreased values for the real group ($p < 0.001$) which makes our results robust against this, potential, outlier.

We can therefore conclude that the VR group makes the purchase decision in a significantly shorter time. For this reason, we take a closer look at the interactions with the products below.

4.3. Evaluation Process

4.3.1. Time until First Product Interaction

In our experiment the participants do not start interacting with products immediately after the task begins. This leads to a time window at the beginning of each task, in which no interactions take place. This "pause" in interaction can be interpreted as the orientation phase [37, 38], before the customer evaluates and possibly verifies the product selection. Figure 4 shows the values for both groups side-by-side for the times until the first product interaction. The participants in VR waited a mean of 28.3s (std=13.2), while the Real group waited a mean of 32s (std=15.8). The KS-test reports $p = 0.036$ which signified a significantly smaller time spent in the VR task until the first product interaction occurs. Again, the same outlier of 127.9s is

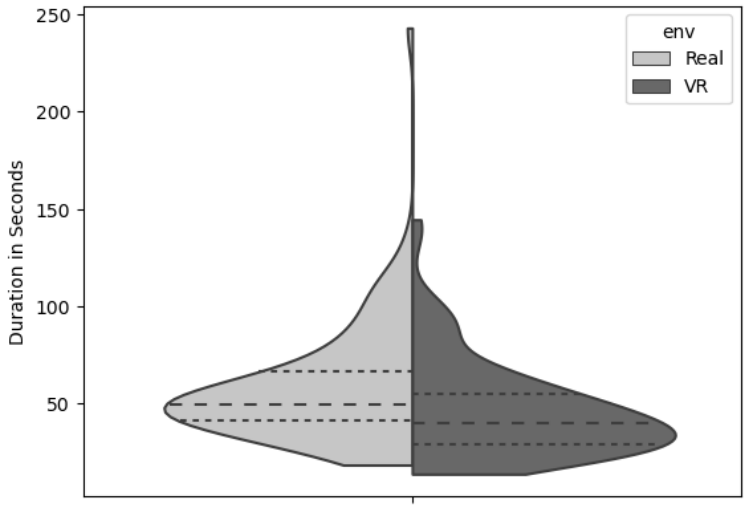

Figure 3: Time until Purchase

visible for the Real group, more than doubling the maximum value of 64.7s of the VR group. By removing the outlier the mean of the Real group is reduced to 31 (std=12.18). Yet, removing the outlier does not change the interpretation, as $p < 0.05$.

4.3.2. Interaction Durations throughout the Task

VR has a significantly smaller mean interaction duration of 6.7s (std=13.7), in comparison to the Real group's mean of 18.1s (std=13.0), KS-test with a p of 0.037. To analyze the interaction durations during the shopping process further, we highlight interaction behavior over time. Figure 5 shows the length of each product interaction (Interaction Duration) in relation to the point of time during the task when the interaction took place (Task Duration). For a better overview, we have divided the task duration into 4 quartiles and plotted the interactions for each of those individually. This shows all product interactions in the respective treatment, as each data point in this scatter plot corresponds to a distinct interaction. While the VR group displays a small number of outliers further out, on average the VR interactions are much shorter and grouped more tightly. For the first quartile, the VR group shows a higher variance but a lower duration on average. The second quartile has a similar spread between the two groups but again with a lower average duration for VR. The third quartile displays the widest spread

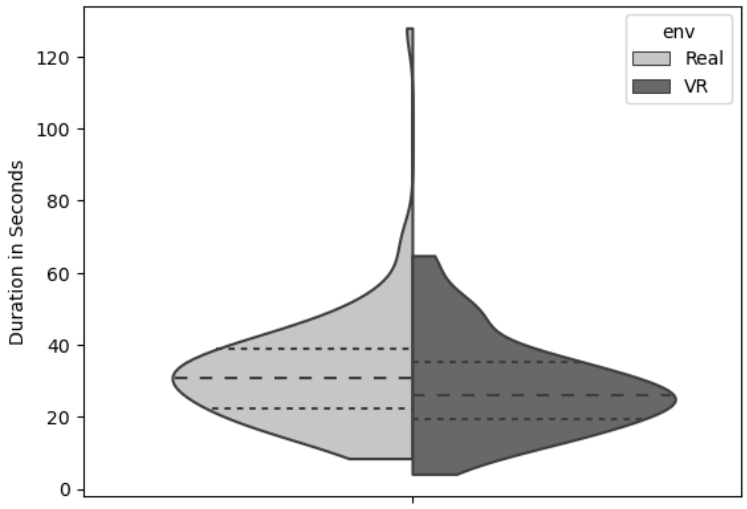

Figure 4: Time until First Product Interaction

in interaction duration for the VR group, with two interactions exceeding 100s. On the other hand, the Real group is grouped tighter in the third quartile than in the second. In the last quartile the VR group's interactions are closer together in both interaction duration, as well as task duration. This last plot highlights the difference in maximum task duration.

While the KS test itself is not limited to one-dimensional data [39, 40], the implementations we rely on in python's *scipy* package however can only handle this case. We therefore utilize *ndtest* (`https://github.com/syrte/ndtest`) to handle this two-dimensional KS test that takes into account both the interaction and task duration. The reported $p < 0.001$ leads us to the conclusion that distribution of interactions and their durations are in fact not comparable.

4.4. Interactions

4.4.1. Interactions over Time

In order to subdivide the analysis of interaction times, we are introducing a distinction. The first interaction with a product is henceforth labeled as a first interaction, while subsequent interactions with the same product are considered repeated interactions.

To narrow the focus and reduce data points, Figure 6 removes all repeated interactions with a given product, therefore containing only the first prod-

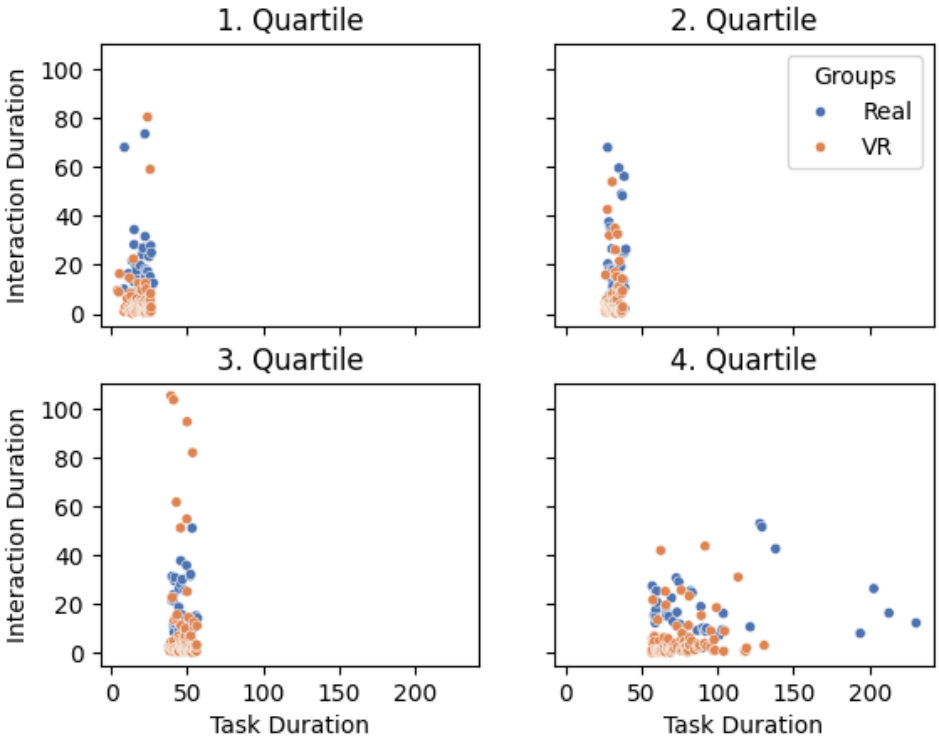

Figure 5: Interaction Duration

uct interactions. The Y-axis therefore represents each subsequent product that a participant interacts with over the course of the task and the inherent purchase decision. A product interaction is defined as any moment a new product is physically grabbed by a participant, indicating a potential interest or evaluation of the product. The scale begins at zero (no product interacted with), and increments reflect the cumulative count of different products interacted with. Each point plotted on the graph signifies the occurrence of a new product being grabbed, thereby providing insights into the pattern and intensity of consumer engagement with different products over time.

The Real group interacted with a maximum of 6 different products, while the VR group had a maximum of 7. Both graphs show that as time goes on, more products are interacted with. The 2D KS test reports $p = 0.23$, which means the number of different products interacted with over time is comparable.

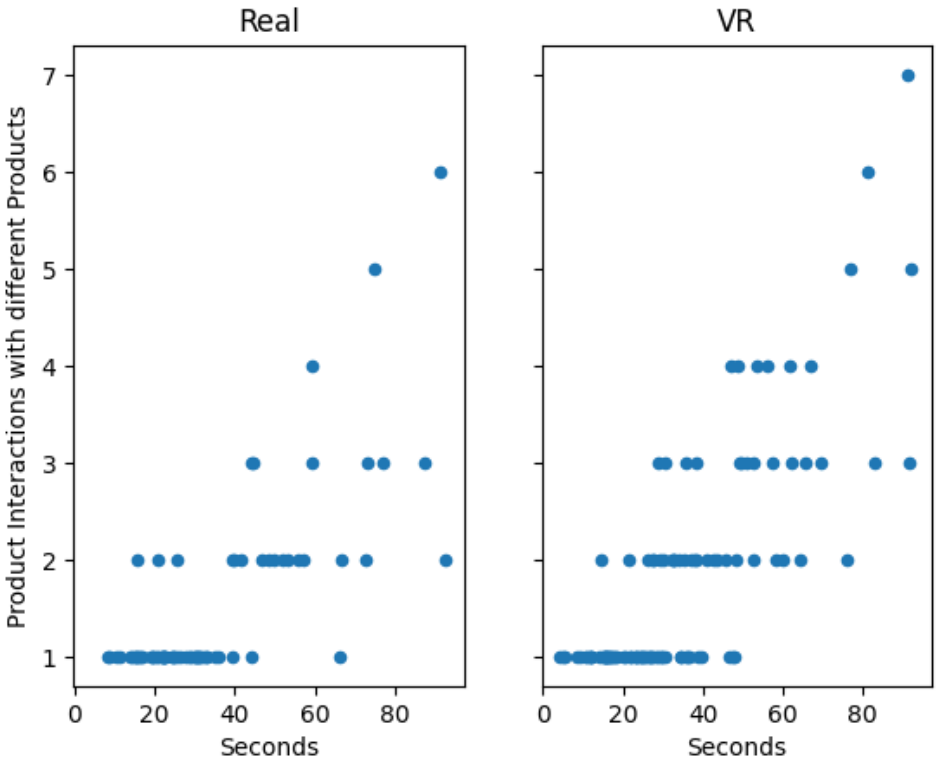

Figure 6: All First Interactions with Products

4.4.2. Different Products

We continue with the number of different products each participant has interacted without considering the point of time that happens. In Figure 7 we show the percentage of participants who interacted with the respective number of products. In the Real group 75.6% of participants only ever interacted with a single product in the task, while the same is true for 70% of the VR group. The VR group interacts with a mean of 1.9 (std=1.27) different products, while the Real group with 1.55 (std=1.0) different products. With the KS test reporting $p = 0.995$, this difference is not significant. Figure 8 provides further details in the number of products interacted with. The plot, again, shows that there is little difference and it also displays a steady drop in the number of products. In VR, for example 16.4% purchased after two interactions with different products while this is 15.6% in reality. It further

drops to 7.5% and 6.7%, respectively.

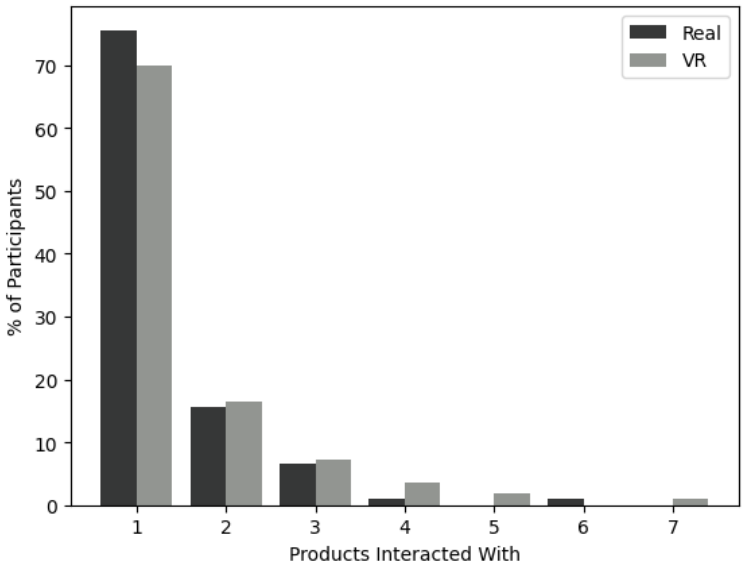

Figure 7: First Product Interactions

4.4.3. Repeated Products

Adding on to this, we now analyze the repeated interactions with the same products. Figure 9 shows the percentage of participants who performed the respective number of repeated product interactions. In both groups $> 60\%$ of participants never interacted with the same product twice, with VR at 61.8% and Real at 66.7%. Visually, the approximate curve for the VR group has a longer tail – displaying participants with up to 21 repeated product interactions. But the KS test does not indicate relevant differences with a p of 0.151.

4.4.4. Time spent with X_{th} Product

Having separated the interactions into the different products, we can measure the duration of each product interaction. Table 4 displays the duration of interactions with the X_{th} product. For the first product the VR group has a mean duration of 4.8s (std=8.04) in comparison to the Real group displaying a mean of 18.44s (std=14.22). This difference also applies to the following products, with 7.34s (std=12.14) against 19.55s (std=11.47) for

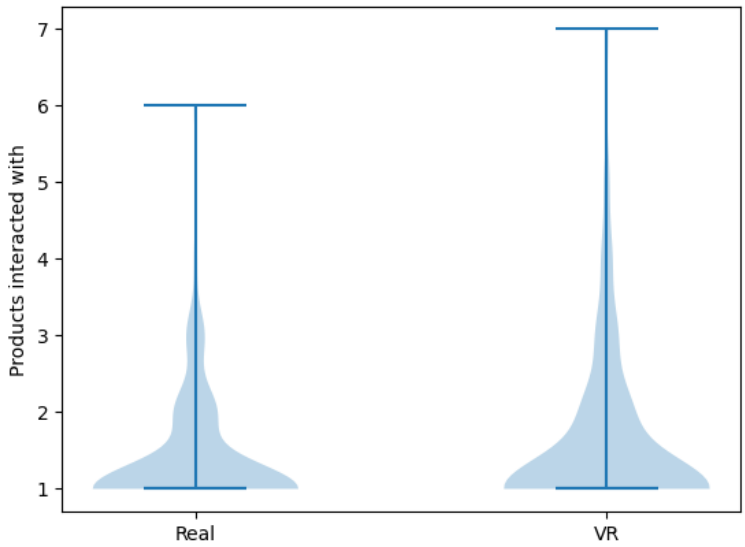

Figure 8: Comparing the Number of Products

the second, 11.77s (std=25.48) and 15.77s (std=7.26) for the third product. It should be noted that only a small number of interactions with more than three products were recorded. Generally, exploring subsequent product interactions further, the time spent with the n_{th} product demonstrates significant differences between our groups.

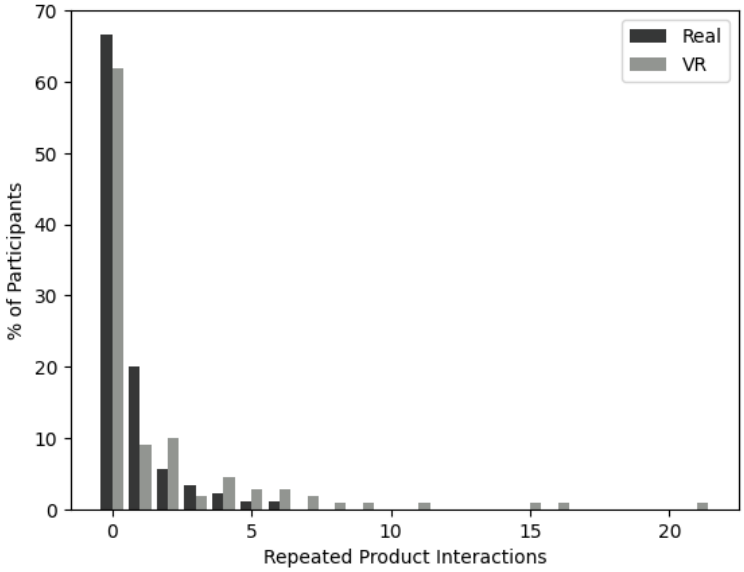

Figure 9: Repeated Product Interactions

5. Conclusion

We can summarize the results for the VR and Real groups as follows: In terms of purchasing decisions, we observe parity of the chosen price and brands between the two environments. However, VR had a significantly higher share of sugar-reduced mueslis being bought. This led us to investigate the evaluation process and the underlying interactions.

A comparative analysis between the two environments reveals a discernible disparity, quantified as a 12-second difference in the average time to purchase. Part of this longer time to purchase in the Real environment may be due to the switch from the VR to the Real environment in the experimental design. However, as the latency before the first product interaction is only 4 seconds in the Real environment, there appears to be a fundamental difference in the length of the purchase process.

Despite these difference in the evaluation process, both groups are comparable in regards to how many different products participants interact with, and how many times one of these products is picked up repeatedly. A difference lies in the length of the individual interactions which is remarkable with 6.7s for VR and 18.1s for the Real group. Some qualitative feedback

Table 4: Duration of Product Interactions

	Interactions	Mean Duration	Std.Dev.
VR Product #1	187	4.8s	8.04
Real Product #1	121	18.44s	14.22
VR Product #2	88	7.34s	12.14
Real Product #2	35	19.55s	11.47
VR Product #3	34	11.77s	25.48
Real Product #3	16	15.77s	7.26
VR Product #4	26	12.89s	24.0
Real Product #4	3	10.85s	2.5
VR Product #5	14	5.85s	11.38
Real Product #5	2	10.93s	0.75
VR Product #6	3	13.6s	8.59
Real Product #6	3	11.86s	3.06

from participants indicates that some of the texts on the muesli boxes were hard to read. But if gripping the products or reading text on their packaging had been a major issue, we would expect to see a significantly higher number of repeated interactions and higher length of interactions in VR, which is not the case. This result could then mean good usability and sufficient visual fidelity of our VR setup, but it could also indicate that the product boxes simply were not not being read in VR. Low readability of the technical equipment used in the study, has been reported before [22]. Importantly, the metrics of VR HMDs have advanced a lot in recent years, with the display resolution more than doubling [41] Also, some sensations are not possible in a VR environment, which could mean that interacting with products was simply less interesting because smaller details such as the weight, surface texture and shifting balance while moving cannot be felt directly. Some participants might have compensated for the missing information, while others did not need it for their product selection. Both aspects lend themselves to the higher observed variance in interaction duration in VR. Furthermore, the VR environment requires less care - products do not need to be placed back onto the shelf and cannot be damaged. Another possible explanation for the difference in interaction durations would be that in VR, instead of a single, long interaction, the product was picked up several times, but for a shorter duration. However, adding up the interaction durations for the first

product shows this is not the case. The combined first product interaction for Real has an average duration of 25.79s (std=8.16) in comparison to 8.16s (std=11.23) for VR, which clearly highlights that the difference in treatment groups remains.

This is of interest to marketing researchers who focus on analyzing consumers' product choices. For example, estimating user preference in VR setups using conjoint approaches that estimate preferences based on user choice could be used to predict behavior in real-world stores. Overall, it might show that the final purchase behavior is not as different between reality and VR. A finding that contradicts comparisons between eCommerce and VR-shopping, which has found some difference [13]. If, on the other hand, the behavior data is used to personalize recommendations or to feed assistance algorithms, e.g. concerning the point of time when help is needed [42] or identifying search motives [43], differences between environments can be expected. This is important for designers of future VR retail shopping environments, as specifics of behavior in VR need to be taken into account. But our results also suggests a promising level of generalizability and transferability of user behavior between virtual and physical environments. However, the nuanced observation that more granular levels of behavior, such as individual interactions and time intervals, exhibit pronounced disparities warrants careful consideration. Understanding the divergence in fine-grained behaviors can inform the refinement of VR interactions, ensuring that the virtual environment authentically mirrors users' expectations and responses.

Our work is limited to the type of purchase we asked our participants to make. Muesli is a low-involvement, low-cost purchase that usually does not involve extensive deliberation, which in turn limits the range of data available to us. This also means that the entertainment aspects of shopping only play a minor role in our results. While this is an intended effect of our clean experimental design, which focuses heavily on the product selection in front of a shelf, it is even more pronounced than expected. Furthermore, our real-world data was collected by manually annotating video recordings and extracting these annotations into a data set. This leaves minimal room for human error in individual data points, but it was controlled for by having multiple annotators. And although our environments closely mimicked a supermarket shelf, having an entire floor be the environment could have additional effects on participants.

Due to the high fidelity and fine-grained data gathering and observability of VR, it is tremendously interesting for conducting experiments. Our

work can be built upon in various ways, such as looking at high-involvement or high-cost purchases, that have the potential to yield different shopping behaviors. Especially for products, where up-front product information research is needed, the results could potentially differ drastically due to the research involved before entering any shopping environment. In addition, our experimental environment was only a separate shelf and not a complete store. Here, a more extensive environment, other customers or interaction with employees could provide insightful data. Lastly, VR is capable of altering purchase environment based on the requirements of the customer, and is even able to provide experiences that are not feasible in reality. Research into adaptive environments or even entirely new shopping concepts could provide customers with additional benefits long term.

While our research was limited in scope to focus on a clean comparison between environments, we are confident, that the results can also be generalized. We have assessed the validity of VR data and measurements when applied to a real-world scenario, specifically in the context of physical brick-and-mortar stores. This has implications for conducting experiments in a tightly controlled environment, improving factors such as validity and reproducibility. Additionally, we highlighted how the wealth of VR data available makes a detailed examination of user behavior possible, facilitating a finer-grained analysis. Ultimately, VR is a tool to turn a given scenario into an experience - and people use these environments in a comparable manner.

References

[1] R. Yazid, S. Shabarudin, A. Mazlan, Virtual reality game mechanics: A review, AIP Conference Proceedings 2808 (1) (2023).
URL `https://pubs.aip.org/aip/acp/article/2808/1/060002/2891850`

[2] M. Wölfel, D. Hepperle, C. F. Purps, J. Deuchler, W. Hettmann, Entering a new Dimension in Virtual Reality Research: An Overview of Existing Toolkits, their Features and Challenges, in: 2021 International Conference on Cyberworlds (CW), 2021, pp. 180–187.

[3] J. Radianti, T. A. Majchrzak, J. Fromm, I. Wohlgenannt, A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda, Computers & Education 147 (2020) 103778.

URL https://www.sciencedirect.com/science/article/pii/S0360131519303276

[4] A. Berni, Y. Borgianni, Applications of Virtual Reality in Engineering and Product Design: Why, What, How, When and Where, Electronics 9 (7) (2020) 1064.
URL https://www.mdpi.com/2079-9292/9/7/1064

[5] N. Xi, J. Hamari, Shopping in virtual reality: A literature review and future agenda, Journal of Business Research 134 (2021) 37–58.

[6] D. Shravani, P. Y. R, P. V. Atreyas, S. G, VR Supermarket: a Virtual Reality Online Shopping Platform with a Dynamic Recommendation System, in: 2021 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR), 2021, pp. 119–123.

[7] M. Meißner, J. Pfeiffer, T. Pfeiffer, H. Oppewal, Combining virtual reality and mobile eye tracking to provide a naturalistic experimental environment for shopper research, Journal of Business Research 100 (2019) 445–458.

[8] D. Hepperle, M. Wölfel, Similarities and Differences between Immersive Virtual Reality, Real World, and Computer Screens: A Systematic Scoping Review in Human Behavior Studies, Multimodal Technologies and Interaction 7 (6) (2023) 56.
URL https://www.mdpi.com/2414-4088/7/6/56

[9] M. Hernández-de Menéndez, A. Vallejo Guevara, R. Morales-Menendez, Virtual reality laboratories: a review of experiences, International Journal on Interactive Design and Manufacturing (IJIDeM) 13 (3) (2019) 947–966.
URL https://link.springer.com/article/10.1007/s12008-019-00558-7

[10] A. Innocenti, Virtual reality experiments in economics, Journal of Behavioral and Experimental Economics 69 (2017) 71–77.

[11] T. Klieštik, A. Novák, G. Lăzăroiu, Live Shopping in the Metaverse: Visual and Spatial Analytics, Cognitive Artificial Intelligence Techniques and Algorithms, and Immersive Digital Simulations, Linguistic

and Philosophical Investigations 21 (21) (2022) 187–202.
URL https://www.ceeol.com/search/article-detail?id=1045822

[12] E. Swilley, Moving Virtual Retail into Reality: Examining Metaverse and Augmented Reality in the Online Shopping Experience, Looking Forward, Looking Back: Drawing on the Past to Shape the Future of Marketing (2016) 675–677.
URL https://link.springer.com/chapter/10.1007/978-3-319-24184-5_163

[13] M. Meißner, J. Pfeiffer, C. Peukert, H. Dietrich, T. Pfeiffer, How virtual reality affects consumer choice, Journal of Business Research 117 (2020) 219–231.

[14] C. Lombart, E. Millan, J.-M. Normand, A. Verhulst, B. Labbé-Pinlon, G. Moreau, Effects of physical, non-immersive virtual, and immersive virtual store environments on consumers' perceptions and purchase behavior, Computers in Human Behavior 110 (2020) 106374.
URL https://www.sciencedirect.com/science/article/pii/S0747563220301278

[15] I. Maggioni, S. Sands, R. Kachouie, Y. Tsarenko, Shopping for well-being: The role of consumer decision-making styles, Journal of Business Research 105 (2019) 21–32.

[16] F. Massara, S. S. Liu, R. D. Melara, Adapting to a retail environment: Modeling consumer–environment interactions, Journal of Business Research 63 (7) (2010) 673–681.
URL https://www.sciencedirect.com/science/article/pii/S0148296309001428

[17] C. Peukert, C. Weinhardt, O. Hinz, W. M. P. van der Aalst, Metaverse: How to Approach Its Challenges from a BISE Perspective, Business & Information Systems Engineering 64 (4) (2022) 401–406.
URL https://link.springer.com/article/10.1007/s12599-022-00765-9

[18] G. K. Sriram, A comprehensive survey on metaverse, International Research Journal of Modernization in Engineering Technology 4 (2) (2022) 772–775.

URL https://www.irjmets.com/uploadedfiles/paper/issue_2_february_2022/19105/final/fin_irjmets1644860607.pdf

[19] F. Spagnolo, P. Corsonello, F. Frustaci, S. Perri, Design of a Low-Power Super-Resolution Architecture for Virtual Reality Wearable Devices, IEEE Sensors Journal 23 (8) (2023) 9009–9016.

[20] H. Kim, Y.-T. Kwon, H.-R. Lim, J.-H. Kim, Y.-S. Kim, W.-H. Yeo, Recent Advances in Wearable Sensors and Integrated Functional Devices for Virtual and Augmented Reality Applications, Advanced Functional Materials 31 (39) (2021) 2005692.

[21] L. Jensen, F. Konradsen, A review of the use of virtual reality head-mounted displays in education and training, Education and Information Technologies 23 (4) (2018) 1515–1529.
URL https://link.springer.com/article/10.1007/s10639-017-9676-0

[22] C. Peukert, J. Pfeiffer, M. Meißner, T. Pfeiffer, C. Weinhardt, Shopping in Virtual Reality Stores: The Influence of Immersion on System Adoption, Journal of Management Information Systems (2019).

[23] B. Shen, W. Tan, J. Guo, L. Zhao, P. Qin, How to Promote User Purchase in Metaverse? A Systematic Literature Review on Consumer Behavior Research and Virtual Commerce Application Design, Applied Sciences 11 (23) (2021) 11087.
URL https://www.mdpi.com/2076-3417/11/23/11087

[24] G. Pizzi, D. Scarpi, M. Pichierri, V. Vannucci, Virtual reality, real reactions?: Comparing consumers' perceptions and shopping orientation across physical and virtual-reality retail stores, Computers in Human Behavior 96 (2019) 1–12.
URL https://www.sciencedirect.com/science/article/pii/S0747563219300603

[25] G. Pino, C. Amatulli, R. Nataraajan, M. de Angelis, A. M. Peluso, G. Guido, Product touch in the real and digital world: How do consumers react?, Journal of Business Research 112 (2020) 492–501.

[26] A. T. Ranaweera, B. A. S. Martin, H. S. Jin, What you touch, touches you: The influence of haptic attributes on consumer product impressions, Psychology & Marketing 38 (1) (2021) 183–195.

[27] S. W. Karangi, B. Lowe, Haptics and brands: The effect of touch on product evaluation of branded products, Journal of Consumer Behaviour 20 (6) (2021) 1480–1496.

[28] J. Peck, T. L. Childers, To have and to Hold: The Influence of Haptic Information on Product Judgments, Journal of Marketing 67 (2) (2003) 35–48.

[29] C. Jansson-Boyd, N. Marlow, Not only in the eye of the beholder: Tactile information can affect aesthetic evaluation, Psychology of Aesthetics, Creativity, and the Arts 1 (3) (2007) 170–173.

[30] H. N. J. Schifferstein, C. Spence, Multisensory Product Experience, in: Product Experience, Elsevier, 2008, pp. 133–161.

[31] M. Nabioyuni, D. A. Bowman, An Evaluation of the Effects of Hyper-Natural Components of Interaction Fidelity on Locomotion Performance in Vi, International Conference on Artificial Reality and Telexistence (2015).
URL http://www.cs.ucf.edu/courses/cap6121/spr2022/readings/fidelity2015.pdf

[32] J. Seibert, D. M. Shafer, Control mapping in virtual reality: effects on spatial presence and controller naturalness, Virtual Reality 22 (1) (2018) 79–88.

[33] F. Fahmi, K. Tanjung, F. Nainggolan, B. Siregar, N. Mubarakah, M. Zarlis, Comparison study of user experience between virtual reality controllers, leap motion controllers, and senso glove for anatomy learning systems in a virtual reality environment, IOP Conference Series: Materials Science and Engineering 851 (1) (2020) 012024.
URL https://iopscience.iop.org/article/10.1088/1757-899x/851/1/012024/meta

[34] A. S. Atalay, H. O. Bodur, D. Rasolofoarison, Shining in the Center: Central Gaze Cascade Effect on Product Choice, Journal of Consumer Research 39 (4) (2012) 848–866.

[35] M. Speicher, P. Hell, F. Daiber, A. Simeone, A. Krüger, A virtual reality shopping experience using the apartment metaphor, in: Proceedings of the 2018 International Conference on Advanced Visual Interfaces, ACM, 2018, pp. 1–9.

[36] R. J. Kosinski, A literature review on reaction time, Clemson University 10 (1) (2008) 337–344.

[37] Kerstin Gidlöf, Annika Wallin, Richard Dewhurst, Kenneth Holmqvist, Using Eye Tracking to Trace a Cognitive Process: Gaze Behaviour During Decision Making in a Natural Environment, Journal of Eye Movement Research 6 (1) (2013).
URL `https://bop.unibe.ch/jemr/article/view/2351`

[38] J. E. Russo, F. Leclerc, An Eye-Fixation Analysis of Choice Processes for Consumer Nondurables, Journal of Consumer Research 21 (2) (1994) 274.

[39] J. A. Peacock, Two-dimensional goodness-of-fit testing in astronomy, Monthly Notices of the Royal Astronomical Society 202 (3) (1983) 615–627.

[40] G. Fasano, A. Franceschini, A multidimensional version of the Kolmogorov–Smirnov test, Monthly Notices of the Royal Astronomical Society 225 (1) (1987) 155–170.

[41] A. Mehrfard, J. Fotouhi, G. Taylor, T. Forster, N. Navab, B. Fuerst, A Comparative Analysis of Virtual Reality Head-Mounted Display Systems, arXiv.org, arXiv.org, 2019.

[42] T. Weiß, J. Pfeiffer, Consumer Decisions in Virtual Commerce: Predict Good Help-timing based on Cognitive Load, Journal of Neuroscience, Psychology, and Economics (2024).

[43] J. Pfeiffer, T. Pfeiffer, M. Meißner, E. Weiß, Eye-Tracking-Based Classification of Information Search Behavior Using Machine Learning: Evidence from Experiments in Physical Shops and Virtual Reality Shopping Environments, Information Systems Research 31 (3) (2020) 675–691.

Should I Zoom You After the Metaverse? The Virtual Reality Perspective on Selecting Computer-mediated Communication Technologies

Tobias Stejskal, Jella Pfeiffer

[a]*Justus Liebig University Giessen, Licher Straße 74, 35394, 35394 Giessen, Germany*

Abstract

Effective communication is critical in many areas of life, and especially in an institutional context choosing the right software can be crucial. Selecting the wrong solution can lead to technical difficulties, misunderstandings, incompatibilities, and communication challenges. The problem is compounded by the fact that most communications solutions have limited or no compatibility with each other. By using concepts from virtual environments research, we can combine several theories of computer-mediated communication into a comprehensive tool. The result is the "Comparing Communication Technology Suitability" (CoCoTeS) model. This model provides a framework for selecting the most appropriate communication software for a given situation. We seek to enable more productive and successful communication outcomes in various contexts, improving collaboration, problem solving and decision making. The CoCoTeS Model also serves as a basis for further research on the effects of computer-mediated communication.

Keywords:
Technology Adoption, Virtual /Augmented Reality, Interpersonal, Consumers and ICTs, Collaboration

Email addresses: tobias.stejskal@wi.uni-giesen.de (Tobias Stejskal), jella.pfeiffer@wi.uni-giessen.de (Jella Pfeiffer)

1. Introduction

Effective communication is essential in many areas of life, including business, education, healthcare, and personal relationships. Choosing the right software can facilitate communication by providing features such as video conferencing, messaging, file sharing, and collaboration tools (Correia et al., 2020; Mora-Jimenez et al., 2022; Sjølie et al., 2022; Salisbury et al., 2006). However, choosing wrong can lead to technical difficulties, misunderstandings, incompatibilities and communication challenges (Calvert, 2005; Correia et al., 2020; Sjølie et al., 2022). Unlike many older means of communication, those in use today are very often incompatible with each other (Arnold et al., 2020; Becker et al., 2021; Bourreau and Kraemer, 2022; Burbury et al., 2021; Fernández-Batanero et al., 2022; Lieux et al., 2021). Instead, users of each solution are isolated from other solutions, leading regulators to consider the creation of a legal requirement such as the Digital Markets Act (EU) 2022/1925 (Cennamo et al., 2023) to reduce reliance on Big Tech companies. This, in turn, means that once a software solution has been established, it requires a great deal of effort to change over. In essence, this is a vendor lock-in (Clement et al., 2017). This means that a good selection process is essential to minimizing future expenses.

Companies do not sufficiently consider communication processes when selecting a technology (Aranda et al., 2006; Fiol and O'Connor, 2003; Sun, 2013; Sun et al., 2016). Instead, they adopt and replace technologies in their search for a suitable candidate (Abrahamson, 1991), for example by considering solutions that their different partners use. This method does not optimize the communication process (Kalla, 2005; Salisbury et al., 2006) , but it does minimize the organization's risk. This effectively means that companies are not currently selecting the most suitable computer-mediated communication (CMC) technologies for their needs (Abrahamson, 1991; Sun et al., 2016; Tingling and Parent, 2004). But how to improve this process is unclear (Shehabuddeen et al., 2006). Identifying what makes communication solutions suitable provides valuable insights into improving software selection for different communication tasks (Laitinen and Valo, 2018). An analysis of the user requirements can lead to a better fit between technology and organizational needs (Tingling and Parent, 2004). The available tools can then be compared against the identified requirements (Sehra et al., 2014; Toan et al., 2022). This requires a strong overview of institutional needs (Tingling and Parent, 2004). Jasperson et al. (2005) argue that use and acceptance of

an information system are influenced by factors such as the perceived usefulness and ease of use, social norms, and organizational context. But having users test technologies does not yield ideal results and should be supported with complimentary analyses (Tan et al., 2009; Wang and Caldwell, 2002). Selecting a suitable communication technology for a given use case requires a different methods and approaches, which we would like to add to. To synthesize our CoCoTeS Model, we approach different CMC theories from the perspective of Virtual Reality (VR). We base this selection of theories on work by Walther (2011) and extended it.

VR has the potential to change the way we communicate and interact with others (Biocca and Levy, 2013; van Brakel et al., 2023; Zamanifard and Freeman, 2023). VR can create immersive environments that provide users with a sense of telepresence, feeling as if they are physically present in the same space as others (Steuer et al., 1995). Using VR as perspective to analyze CMC technologies from allows us to examine how to facilitate more effective digital communication, particularly when face-to-face is not an option (Solska, 2022). By applying a VR lens to CMC technologies, we create an overarching concept to several CMC theories. Reviewing CMC theories from within the concepts of VR, we derive relationships between established concepts and create the "Comparison of Communication Technology Suitability" (CoCoTeS) model. This also addresses the call by Carr (2020) to "increasing the focus on the process of mediation in human communication." By adopting a technology-agnostic approach, we unify mediated communication across different platforms and contexts.

We consider VR an advanced CMC technology that is not limited to communication, but has central social components (Biocca and Levy, 2013). We highlight our grounding theories and then introduce the necessary terms and concepts from VR literature. The result is a visually distinct overview of technological and personal aspects that influence each other. This technology-mediated model allows for asymmetrical technologies and capabilities to be considered. This is achieved by utilizing the VR concepts for encoding and decoding information. On the users' side we build on social presence and other CMC theories to form clear relationships that can be reasoned about. Our CoCoTeS Model can create a systematical understanding of the technology, rather than just describing economical risk, functionality, or value assessment. As it heavily relies on CMC theories, we implicitly provide an abstraction of a larger set of theories, that each assess different characteristics of technologies.

Through a series of fictional use cases and different user stories we demonstrate, that the CoCoTeS Model serves as a framework for selecting the most appropriate communication technology. This should improve communication outcomes, collaboration, and decision-making when applied. It can be basis further research that applies, extends, or refines it.

2. Computer-mediated Communication

Given the rapid innovation of communication technologies, our working definition for CMC - "any human communication achieved through, or with the help of, computer technology" (Alice et al., 2004) does not prescribe the form of the technology. Instead, it focuses on the process by which people transmit information through electronic means. By solely considering it a process where people use a technology capable of encoding, decoding and transmitting signals to create, exchange and perceive information (Alexander Romiszowski and Robin Mason, 2013) we are missing a crucial aspect. "CMC, of course, is not just a tool; it's at once technology, medium, and engine of social relations. It not only structures social relations, it is the space within which the relations occur and the tool that individuals use to enter that space" (Jones, 1995). It therefore includes both the transmission mechanisms derived from communication theory and the significance of interaction between people mediating the technologies and processes (Naughton, 1992).

The selection of communication tools should instead be based on suitability in achieving the bottom line of the business goal and how they fit in (Kalla, 2005). But companies are not currently selecting well suited CMC technologies (Abrahamson, 1991; Sun et al., 2016; Tingling and Parent, 2004). And how to make this decision is basically unclear (Shehabuddeen et al., 2006). A thorough analysis can lead to a better fit between technology and organizational needs (Tingling and Parent, 2004). Technologies can then be compared against the identified requirements (Sehra et al., 2014; Toan et al., 2022). Dhillon and Backhouse (2001) argue that institutions should employ a cost-benefit approach and to prioritize based on likely impact. But this requires a strong overview over all needs (Tingling and Parent, 2004) and Jasperson et al. (2005) argue that continued use and acceptance are influenced by various factors such as the perceived usefulness and ease of use of the technology, social norms, and organizational context, which should be supported with complimentary analyses (Tan et al., 2009; Wang and Caldwell, 2002). Lee (2010) found that CMC is the most frequently used channel

for employees but that face-to-face communication is perceived to be more effective for relationship building.

Technology selection requires a combination of different methods and approaches that often are highly theoretical. A customer would not apply communication theories to inform their choice. Our model is a new method, that has a lower barrier to entry and is still theoretically grounded. It provides a holistic perspective, gathers individual scientific concepts and makes their relationships transparent. It is a way to structure limitations and possibilities of technologies – covering social cues, information, but also inter-personal and personal factors. To synthesize our CoCoTeS Model, we start with a set of theories selected by Walther (2011). We added Media Naturalness Theory due to its usage in similar works (Kaye et al., 2022). Each theory is briefly review as is relevant to our model. These are purpose-driven and should by not be taken as generally comprehensive.

Beginning with digital interaction between people, the Social Presence Theory suggests that people interact with technology similarly to how they interact in face-to-face communication (Hiltz et al., 1978; Short et al., 1976). It examines the extent to which individuals experience others as being present. It relates to both individuals feeling connected to in a mediated communication environment (Lee, 2004). It assumes that communication technologies vary in their ability to create a social presence. Social Presence Theory has been used to explain a range of phenomena that appear in online learning, virtual teams, telemedicine, and others (Biocca et al., 2003). Social presence of face-to-face situations is considered the gold standard (Hauber et al., 2005). The possible social presence depends on the communication channel to provide social cues (Hauber et al., 2005). These cues are essentially signals that one expresses to influence others (Adams et al., 2017). In their work to imitate human communication, Seeger et al. (2021) group them into verbal, non-verbal and human identity cues. Extensive research has gone into exploring social presence in the context of Virtual Reality (VR) and has been found to provide a high level of social presence with conversation patterns that are very similar to face-to-face interaction (Smith and Neff, 2018). The quality of collaborative virtual reality is based on the experienced social presence (Biocca and Levy, 2013). A positive social presence corresponds with good communication outcomes (Biocca and Levy, 2013; Lee and Nass, 2005).

To transmit many different social cues, the Media Richness Theory must be considered relevant. It states that communication media have different capabilities to convey information, and that the communication medium should

be matched to the message (Daft and Lengel, 1983; Daft et al., 1987). Communication mediums can be categorized based on their ability to provide immediate feedback, to convey multiple cues, to allow for personalization, and to handle complex messages. Simple messages can be effectively communicated using lower richness media, while complex messages require richer media to ensure effective communication. The theory has been widely applied in organizational communication contexts, such as decision-making processes and information sharing, and has influenced the development of various communication technologies (Daft et al., 1987).

Building on Media Richness Theory is Media Naturalness Theory, which focuses on the information-processing capabilities with communication channels. It argues that communication through face-to-face interactions is the most effective form of communication (Kock, 2004, 2005, 2007), which is similar to other Cues-Filtered-Out theories like Social Presence Theory and Media Richness Theory. It suggests that other forms of communication are less effective because they lack the natural cues present in face-to-face communication, such as body language. Accordingly, humans need to adapt to new forms of communication, and they do not come naturally to them. It has been criticized for oversimplifying the complexity of communication and ignoring the potential benefits of mediated communication, such as increased accessibility and convenience (Hantula et al., 2011).

More natural communication technologies should increase the potential for social influence and Social Influence Theory explores how individuals' attitudes, beliefs and behaviors are influenced by others in social interactions (Kelman, 1958). It examines processes such as conformity, obedience and persuasion in how social influence operates, by identifying three primary forces of influence: Complying with an external influence for a reward, identifying with an entity influencing them or internalizing the presented values due to their perceived validity.

However, communication is not a rigid construct that takes a predictable course. Especially when technology separates the participants, unexpected behaviors can result. Channel Expansion Theory proposes that a technology's potential is heavily influenced by the user's experience with the technology (Carlson and Zmud, 1999; D'Urso and Rains, 2008). It suggests that as users become more familiar and comfortable with a technology, they will develop more effective ways of using it for communication purposes. This, in turn, expands the channel of communication and enables users to communicate more effectively and efficiently. This means that a variety of factors, such

as training, feedback, and user interface design can improve a technology's suitability. By improving the user experience, the technology's potential to facilitate communication can be expanded, allowing for more effective communication to take place. Similarly, Social Information Processing Theory suggests that social cues can be conveyed through textual cues such as language, punctuation, and emoticons. It explains how individuals develop relationships through CMC (Salancik and Pfeffer, 1978; Walther, 1992). Despite the lack of some social cues, individuals can still form impressions and develop relationships over time. Unique language patterns convey their personality traits, emotions, and intentions. They are processed over time, leading to the formation of social impressions and relationships.

The Hyperpersonal model follows this line of thinking, by suggesting that individuals can develop more intense and intimate relationships online than they can face-to-face (Walther, 1996; .20, 2011). It links selective self-presentation, the ability to manipulate communication cues, and controlling the pace of communication to relationship building. Accordingly, people are more likely to reveal intimate information and form strong emotional connections online due to the reduced social cues and increased control over self-presentation (Walther, 1993). However, the model also acknowledges that these relationships may not always be sustainable and are susceptible to idealization and misrepresentation (Walther, 2011).

By being able to influence the self-representation, individuals can stay anonymous or mislead about their identity. The Social Identity Model of Deindividuation Effects examines anonymity and social identity effects on individual behavior in CMC (Diener, 1980; Lea and Spears, 1992; Postmes and Spears, 1998). It suggests that group norms and identities can influence individual's behavior if they associate with them. Anonymity can amplify these effects by changing the relative salience of personal identity and social identity, leading to altered group behavior (Diener, 1980).

3. System Affordances

In addition to the transmitted information, there is also information that is inserted by the system. Most technologies provide access to functionalities that aid communication. We will refer to these functions that go beyond the transmission of cues between participants as system affordances, as they are unique to CMC and technology dependent. Their value lies in bridging communication gaps, reducing effort, empowering users to express themselves

more easily and making CMC more inclusive. The Office of Communications (2006) found that 80% of television viewers utilize closed captioning for reasons other than hearing loss, which in turn signifies that this affordance benefits more than just those who require them. Smith and Neff (2018) use the term unique affordance in a different context and the term Augmentative Communication Function is directly associated with individuals that have complex communication needs (Beukelman and Light, 2020), which we do not focus on.

Most ICTs offer location and time-independent access to digital information exchange (Walther, 1992). Some technologies might isolate users to some degree, which focuses their attention and can exclude external influences that degrade information exchange (Biocca and Levy, 2013). Adaptive self-representation enables users to adjust their representation. Especially avatar-based technologies excel at personalized self-representation (Biocca and Levy, 2013; Han et al., 2022; Nowak and Fox, 2018), which camera-based systems can only achieve to a lesser degree (Javornik et al., 2022; Jones et al., 2009; Bredikhina, 2020). Here participants can present themselves more authentically and truer to who they are (Campbell et al., 2020). They face less discrimination due to attractiveness (Lee et al., 2015), height (Rosenberg, 2009), or other physical aspects (Puhl et al., 2008) They also influence themselves through their avatar (Beyea et al., 2021) and conceal potentially contentious aspects of themselves (Jiang et al., 2011). Digital objects or digital twins of physical objects can be included in the communication space and collaboratively used (Haldane, 2007; Kim et al., 2021). A digital record of the communication enables reviewing and recalling (Buehling, 2023; Yan et al., 2022). This can be particularly useful when it can be searched (Gangneux, 2019). Language barriers can also be reduced by built-in language translation tools, which can be combined with Text-To-Speech (Kaur and Singh, 2023), generated subtitles (Biao Zhang et al., 2022) even Speech-to-Speech translation (Lee et al., 2022; Roy, 2019). In general, these System Affordances can enable more inclusive and sustainable digital interactions than possible without them.

The effectiveness of CMC is assumed to depend on the specific communication task context, but it can be a fairer basis for communication. Unique affordances have the potential to reduce discrimination and provide a more inclusive, effective, and equitable platform for communication. In specific situations CMC can therefore produce better outcomes than Face-to-Face interactions (Carr, 2020).

4. Cognitive Load Theory

In all communication situations, we must assume that individuals have limited information processing capacities (Miller, 1956). Cognitive Load Theory (Brünken et al., 2010; Sweller, 2011) explains how we process information during learning and problem-solving. The theory rests on the assumption that humans have a limited amount of mental capacity which the brain can process at any given time. The nature of the task can affect how much of this capacity it occupies. Three forms of cognitive load (CL) are identified, which are extraneous, intrinsic, and germane (Sweller, 2011). Extraneous CL refers to the effort to process information that is not a result of the topic. It refers to effort caused by unnecessary information, inappropriate representations of information, and inaccurate instructions. The inherent complexity associated with a task is referred to as intrinsic CL. While the associated difficulty cannot be changed by an instructor, the content could reasonably be subdivided and taught in succession (Chandler and Sweller, 1991). With germane cognitive load describing the effort involved in dealing with information schemas, we follow Sweller et al. (2019) in incorporating it into intrinsic CL.

5. Virtual Reality

Physical reality is perceived as an immediate, first-order sensation and actions in this reality result in direct consequences that follow the laws of physics. In VR this connection between action and reaction does not exist. While interactions are possible, they are governed by a computer simulation. VR can therefore be defined as "interactive computer-generated multimodal second-order sensations, which users perceive as first-order sensations" (Pfeiffer et al., 2020). The degree to which these second-order sensations are perceived as first-order sensations is mainly determined by the immersion, which is limited by the applied technology (Suh and Lee, 2005), but objective and measurable (Bowman and McMahan, 2007; Slater and Wilbur, 1997). The current wave of VR devices is driven by HMDs that pursue the goal of representing a virtual world as an immersive experience through stereoscopic, surrounding vision that dynamically tracks the head rotation and translation (Brooks, 1999; Pan and Hamilton, 2018). Now that this technology is finally widely available to consumers (Xi and Hamari, 2021), its general adoption and use for training and education has become feasible (Pan and Hamilton, 2018).

5.1. Immersion

In line with Slater and Sanchez-Vives (2016) we refer to immersion in the strictly technical sense. We adhere to the immersion taxonomy by Nilsson et al. (2016) and utilize the term System Immersion, hereby representing the technological perspective on virtual environments (VE). This should be regarded as an objectively measurable property of the systems capability to present the transmitted information (Slater, 2003). It is equal to immersion as defined by Slater and Wilbur (1997) as "the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding and vivid illusion of reality to the senses of a human participant".

5.2. Interactivity

In CMC interactivity can be used to express the degree to which communication transcends reaction (**?**). The VR concept for this term differs from this understanding. Steuer et al. (1995) defines the interactivity of a given medium by focusing on three factors that make up the interface that a user has with a given medium. The user can input a range of actions anytime, at a given rate of speed. These inputs need to have a mapping that affects change in the mediated environment. It's not limited to being able to navigate a virtual word, instead representing the power to modify the environment (Ryan, 1999). Its perception can be influenced by individual differences, but it is an important foundation of VR (Mütterlein, 2018; Mütterlein and Hess, 2017).

5.3. Relating VR terminology to CMC

Both VR and CMC aim to enhance communication and interaction among users in this space (Jones, 1995), and to create more immersive and engaging experiences (Biocca and Levy, 2013). They share the concept of mediated communication. This includes social presence, which refers to the feeling of being connected to others in a mediated environment (Walther, 2011). Both researchers are interested in understanding how users interact with and respond to mediated environments and technologies, and how these experiences can be improved. While they clearly are distinct fields, they share a common goal of creating and improving mediated communication and interaction. To successfully adapt VR terminology to CMC, we need to address the fact that terms usually refer to purely virtual and mostly fictional experiences. Therefore, the concepts need to be adapted slightly and their validity in the context of CMC clarified.

5.3.1. System Immersion in CMC

All signals that influence us and others in a social interaction are regarded as social cues (Adams et al., 2017). An obvious attempt at comparing communication technologies would therefore be to list the most relied upon social cues and sum up how many each technology is able to transmit, as these convey information and are necessary for social understanding (Freeth et al., 2013). But due to their vast number, complexity and multidimensional variety "we have to look for them in several areas rather than capturing them in a single unilinear list" (Finnegan, 2005, p.55). Therefore, we rely on System Immersion as a measure to evaluate the coverage of real-world sensory modalities.

System immersion can be seen as a measure of cues-filtered-out because it refers to how far from a first-order sensation the (second-order) technological depiction is. This can include both sensory cues (e.g., sights, sounds, smells), as well as social cues (e.g., body language, facial expressions, tone of voice) (Aburumman et al., 2022; Kwon et al., 2013). The wider coverage of cues a technology provides, and the higher fidelity they are provided in, the higher the level of System Immersion. In a CMC context the medium being used can filter out many of the nonverbal social cues that are present in face-to-face communication (Walther and Parks, 2002). This filtering of cues could make it more difficult for participants to read each other's emotions, understand their intentions, and establish a sense of social presence. Thus, the level of System Immersion in a technology can influence the social presence experienced by users. System immersion is therefore closely related to the concept of cues-filtered-out, as both describe how a communication medium can limit the amount and type of information that is transmitted between participants. When fewer cues are available, participants may need to rely more heavily on other modalities, which can increase cognitive load and reduce the level of social presence experienced during the interaction. System immersion in a CMC describes the extent to which the communication medium makes sensory information available to participants.

5.3.2. Interactivity in CMC

Interactivity in VR covers at what speed users can influence which specific aspects of the technology and which changes result from these actions. One important aspect of interactivity is the provided range of interaction possibilities, which includes the ability to relay social cues to other communication partners. In CMC, social cues can be conveyed through text-based

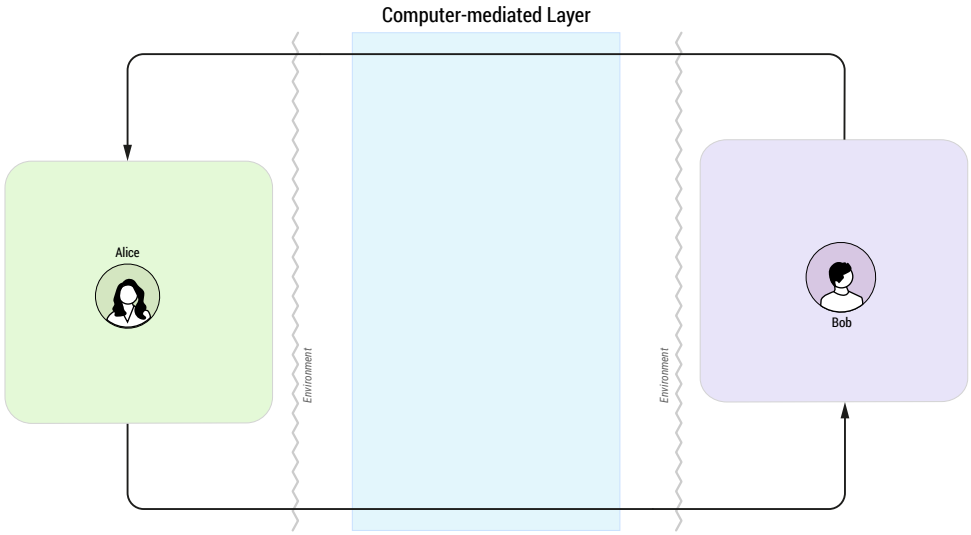

Figure 1: Basic Structure of the CoCoTeS Model [COLORED]

communication by using emoticons, abbreviations, sound or visually. In VEs, users can convey social cues using customized avatars, gestures, sound and behaviors. In CMC, sensory cues are typically limited to sight and sound, but advances in technology are starting to provide opportunities for touch and even smell (Cheok and Karunanayaka, 2018; Dozio et al., 2021; Harley et al., 2018; Serrano et al., 2016). As a result, interactivity needs to describe how users of CMC technologies can encode messages to engage in reciprocal and responsive communication with other participants.

6. Conceptualizing the CoCoTeS Model

6.1. Basic Structure

From this foundation we can now derive our model. While Shannon and Weaver's model is often criticized for being too simplistic and linear (Maras, 2000; Ritchie, 1986), it is often considered a foundational communication model (Ellis and McClintock, 1990; Sabah Al-Fedaghi, 2012). We use it to inform the basis of the CoCoTeS Model (see Figure 1). Shannon (1948) original model has an information source utilizing a transmitter to put a message on a channel, which is in turn picked up by a receiver and forwarded to the

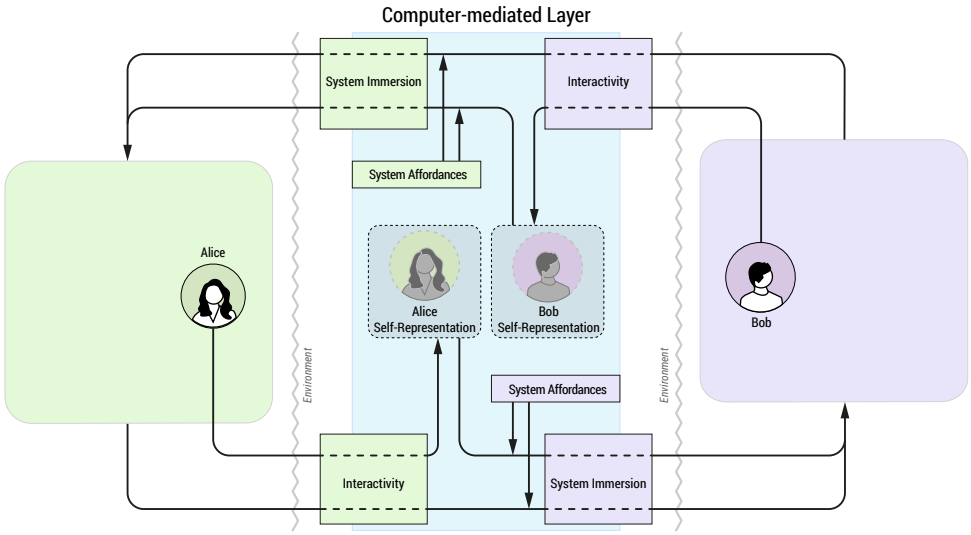

Figure 2: Technological Aspects of the CoCoTeS Model

destination. We chose the communication partners to be represented by Bob and Alice. As our model is concerned with CMC, we designate the central space for a computer-mediated layer. Based on Shannon (1949) concept of a noise source, we incorporate the changing, external influence on the communication process as a barrier that is named environment. Examples are background noise or light reflections. However, since these are situational, we do not further specify them. Barnlund (1970) and Watzlawick et al. (1967) extended the original model into a bidirectional and ongoing process between sender and receiver. In this transactional model, communication is not viewed as a linear process but as a circular one, with each participant influencing the other and vice versa. The upper half of our model therefore has transmissions from Bob to Alice, with the lower half representing transmissions in the other direction (see Figure 1). All transmissions must pass through the computer-mediated layer.

6.2. Focusing on Technology

The encoding step involves the translation of a message into a form that can be transmitted. Interactivity can be linked to the encoding step in the sense that it allows users to translate their thoughts, feelings, and actions into digital signals that can be transmitted. We therefore introduce Interactivity

so that information must pass through on its way into the computer-mediated layer (see Figure 2).

In the CoCoTeS Model, System Immersion refers to the extent to which a message is successfully transferred to the destination side. It can be seen as a measure of the effectiveness of the receiver process in the Shannon-Weaver model of communication, as it indicates the degree to which receiver is allowed to extract the message being encoded by the information source. This does not guarantee the correct interpretation of the message by the destination, which is the communication partner. As both participants are actively encoding and decoding information, they are both assigned their own Interactivity and System Immersion (see Figure 2). This is especially important in non-symmetric communication scenarios, where participants have different technological capabilities available or differing configurations. The last aspect of the computer-mediated layer is based on the Hyperpersonal Model (Walther, 1996; Walther et al., 2015) and Social Information Processing Theory (Salancik and Pfeffer, 1978). We introduce a self-representation for both communication partners similar to Walther et al. (2011) and similar in practice to the relationship of true self and actual self (Bargh et al., 2002). This artificial self-representation can be carefully constructed and tailored to the specific communication medium being used. It therefore exists as a personalized persona, shaped by, and embedded within the medium. This is in line with self-disclosure as both a voluntary and involuntary information transmission. It also allows for the concept of deceptive or misleading self-presentation. Notably, the self-representation is subject to the same limitations that the user faces when interacting with the medium. Users are only able to portray what they can communicate. In short, it is their own image as created through the Interactivity of the medium. To accommodate this relationship, each participant is now depicted to transmit two kinds of information, the self-representation and the information content. While distinct paths exist between modifying the self-representation and transmitting information, it is not necessary for a message to be one or the other exclusively. Participants can carefully craft their messages to present a particular image of themselves, highlighting certain personality traits or downplaying others. But also, the form of a message can influence the self-representation – be it a political leaning (Castro and Vaca, 2017) or an accent invoking certain stereotypes (Gill, 1994). System affordances provide unique functionalities that go beyond the transmission of messages between participants. These affordances, which are specific to a product or technology, bridge communication

gaps, empower users to express themselves more easily, and enhance inclusivity. They can influence how a participant experiences the self-representation of his partner, as well as altering transmitted information that is then presented through System Immersion in an altered state. As both users can select and configure their own system affordances, again both participants are assigned their own.

6.3. Focusing on Users

After outlining the connections in the technology layer, what remains are the personal aspects on the part of the participants. In line with Shannon and Weaver (Shannon, 1948) we first add the Received Information as a concept to each participant's side (see Figure 3). This allows the model to maintain the Received Information and the associated communication partner as independent concepts that influence each other. Additionally, the partner's self-representation is evoking a Social Presence. Both Received Information, as well as Social Presence are affected by the System Immersion that all messages pass through, as a medium's richness predicts increased Social Presence (Nowak et al., 2009). Social Presence is assumed to correspond to good communication (Lee and Nass, 2005). It can be degraded, when a technology makes users feel less connected to others in a communication situation. This can result in a lack of empathy and understanding for others and can lead to a reduction in prosocial behavior. Also propagated communication errors can occur when a misunderstanding or miscommunication is propagated throughout a communication network. People expect consistency in behavior (Lee and Nass, 2005) and we therefore, we propose that Social Presence has a bi-directional interaction with the Received Information. This can also be supported with Social Information Processing Theory (Kelman, 1958), Social Identity Model of Deindividuation Effects (Diener, 1980) and Walther (1996) concept of hyperpersonal reciprocal influence. To account for personal experiences influencing the communication process, we draw on Channel Expansion Theory to identify relevant types (see Figure 3) (Carlson and Zmud, 1999). Starting with the experience with the communication partner and experience with the organizational context, we conceptualize a Social Experience element. Our Social Experience construct therefore refers to the extent to which users are familiar with a given communication scenario. When users have a high degree of social experience with a setting, they may be able to judge similar interactions more, as they are familiar with the norms and conventions in that circumstance. Furthermore, Channel Expansion Theory

posits that experience with the communication technology can lead to an expansion of the user's perceived communication channel (Carlson and Zmud, 1999). This expansion occurs because experienced users become more familiar with its characteristics. As a result, experienced users should be able to communicate more effectively through this technology. This assumption is in line with Media Naturalness Theory's prediction on compensatory adaption (Kock, 2004). Lastly, the experience with the topic is introduced, as an individual's knowledge of a topic should influence his communication. While communicating, all participants experience a Nowak et al. (2009) note people would rather have a task require less effort than more. Drawing on Social Information Processing theory (Salancik and Pfeffer, 1978; Walther, 1992), CMC requires more time and effort, which is inherently less desirable (Kock, 2004). The CL experienced by each communication partner can be affected by factors related to the user's Topical, Social, and Channel Experience. Topical Experience refers to the user's familiarity with the subject matter of the communication, which affects intrinsic CL (de Jong, 2010), as they already have a mental framework for processing the information. Different technologies have their own characteristics, which can affect the extraneous CL of the user. A less rich medium may require the user to spend more mental effort in decoding the message, leading to a higher extraneous CL. Similarly, the user interface for Interactivity is a factor in the experienced extraneous CL. Therefore, we propose that both System Immersion, as well as Interactivity influence the extraneous CL of their respective user, which is consistent with Media Naturalness Theories suggestion that less natural technologies will generate more cognitive effort (Kock, 2004). Channel experience refers to the user's experience in communicating through a particular medium, such as video conferencing or instant messaging. The use of unfamiliar software or hardware should increase the extraneous CL. Inversely, if one is used to dealing with a technology, the peculiarities are less demanding. Therefore, Channel Experience should directly influence extraneous CL. Experienced users may also feel more comfortable with the technology, which reduces extraneous CL. Channel Expansion Theory suggests that users may perceive higher levels of Social Presence through a given system as they become more experienced with the technology and can fully decode even multi-layered messages. This gives them a wider spectrum of signals to receive communication through. Similarly, the Channel Expansion Theory applies to Interactivity, as users need to be aware of interaction possibilities before they can utilize them. Together, this results in a connection from the experiences to both

Interactivity and System Immersion. Similarly, the CL of each user should influence how well information can be encoded and decoded in interaction with the computer-mediated layer (Kalyuga et al., 2003; Paas, 1992; Sweller and Cooper, 1985). Considering all these similar connections, and accounting for personal differences, we decided to use an overarching connection that expresses that each participant influences his corresponding Interactivity and System Immersion (see Figure 3). Some seemingly obvious connections have been ruled out by us after consulting the literature. Neither seem CL and Social Presence to directly affect each other (Homer et al., 2008), nor does the communication partners experiences seem to affect the communication partners CL (Mayer and Mayer, 2005). Instead, a less experienced communication partner can be assumed to transmit information in a form that leads to a higher CL than other situations, which our model already covers. In short, we started from a very basic model of CMC technologies, where they act as a transmission layer for interpersonal communication. The VR concept, Interactivity, encapsulates all available input possibilities. The output to the user is mediated by the System Immersion. Based on the Hyperpersonal and Social Identity Model of Deindividuation Effects, as well as Signaling Theory we introduce a self-representation of the user that can be molded Interactivity. This self-representation is mediated by the System Immersion and transmitted to the partner. All transmitted information is routed through first the Interactivity, then influenced by System Affordances, and ultimately delivered to the user through their System Immersion.

7. Use Case Scenarios

To give an example application of the model, we will now illustrate three use cases. We expect the CoCoTeS Model to be best utilized by first creating two personas of your communication partners, respective user stories and then integrating their personal aspects into the model. Afterwards the technologies are substituted in, with the Channel Experience and CL being technology dependent. Then the differing impacts on the scenario can be observed (see Figure 4).

The following scenarios are chosen to illustrate different strengths of our model. To offer a tangible representation of the intended communication partners, we have chosen to utilize personas (Cooper, 2004). They are designed to embody the characteristics, motivations, and goals of certain typical groups of people. They are fictional in nature but fulfill the purpose of in-

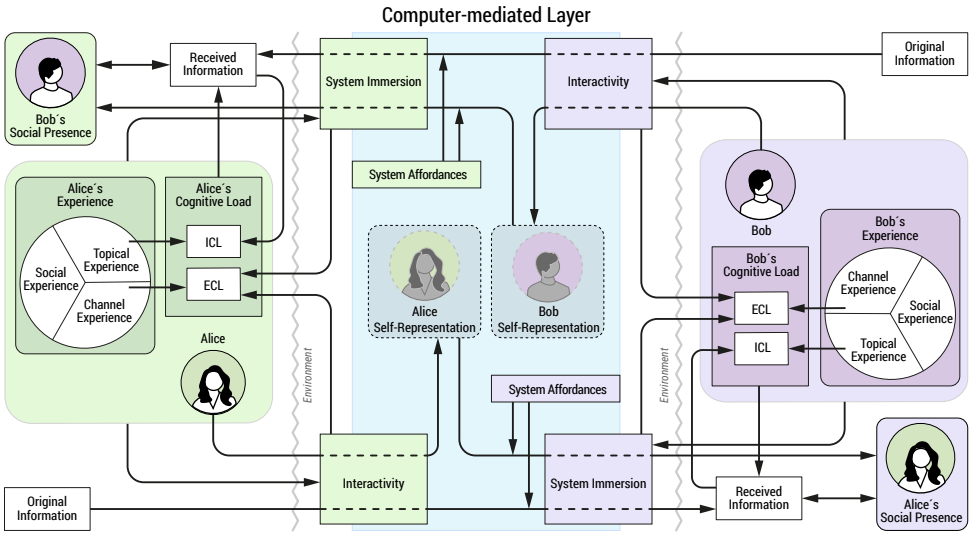

Figure 3: The CoCoTeS Model

forming design decisions in a user-centered way. The design of our personas is informed by Chang et al. (2008) and as suggested by Cohn (2004), we will add two respective user stories and illustrate how they interact with our model. As a basis we will adhere to Lucassen et al. (2016) and utilize the Connextra template to formulate them: "As a <role>, I want <goal>, [so that <benefit>]".

7.1. Highlighting Technology Choice

7.1.1. Preparation

Emily, an accomplished designer, has been commissioned by a high-profile client, Sarah, to create a unique piece of furniture that must seamlessly fit into a predetermined functional and aesthetic spatial context. Emily Anderson, 38, is an accomplished and highly creative designer specializing in bespoke furniture. With over 15 years of experience in the industry, she has established herself as a visionary and innovative designer, known for her ability to seamlessly blend functionality, aesthetics, and sustainability in her creations. After an apprenticeship with a London furniture maker, she completed a bachelor's degree in industrial design. She could be regarded as a perfectionist, that meticulously plans out her designs digitally. To streamline

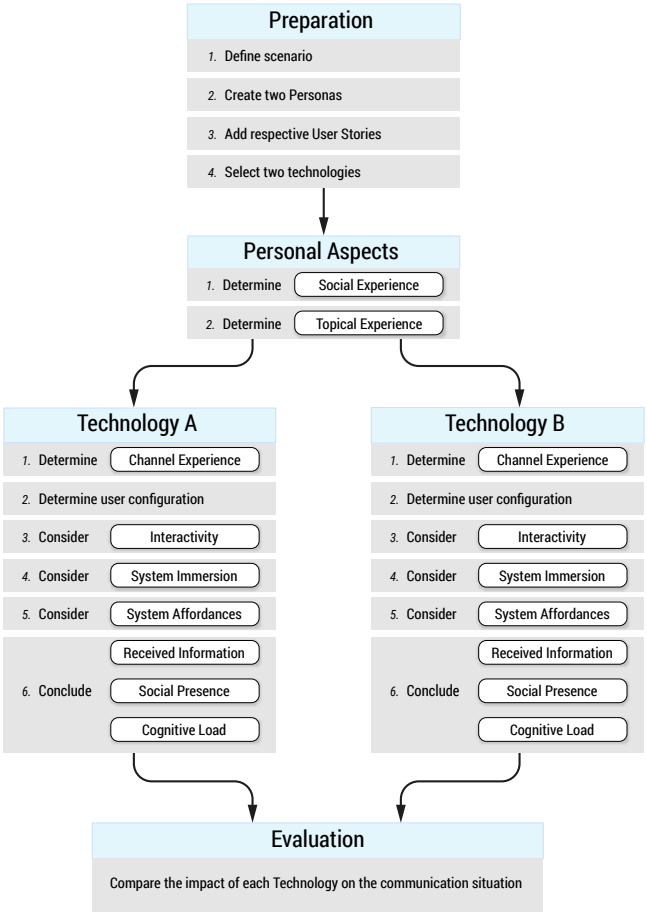

Figure 4: Applying the CoCoTeS Model

her design iterations, she likes to work closely with clients and strongly advocates for sustainable materials and practices. Her highest priority is creating unique and aesthetically pleasing furniture pieces that exceed her clients' expectations. But for her this can only be achieved through clear and efficient communication with her clients, suppliers, and collaborators. To reduce her workload, she optimizes her workflow and seeks to automate repeating tasks. As a designer, Emily wants to efficiently create unmatched designer furniture to satisfy her client and herself. Sarah Mitchell is a successful and busy lawyer with a refined taste for interior design. At the age of 52, she values the finer things in life and understands the importance of creating a sophisticated and comfortable living space. Sarah has recently purchased a luxurious penthouse apartment in Frankfurt and envisions a specific piece of furniture that not only fits seamlessly into her space but also matches the overall aesthetic she has in mind. Due to her busy schedule, Sarah values efficiency and a hands-off approach without extensive research or meetings. She prefers tangible samples and physical mockups to inform her opinion. Ultimately, she is looking for a designer who is reputable, reliable and has a track record of delivering stellar work. As a customer, Sarah wants to be sure to receive an outstanding piece of furniture to her liking without having to be overly involved in the process.

7.1.2. Personal Aspects

Emily has a lot of Social Experience in similar situations, as it is a core part of her professional life. She also has the luxury of being able to decline orders from clients that she personally does not find congenial. Therefore, we assume Emily's Social Experience to be very high. Similarly, her Topical Experience is exceedingly high due to her professional experience. On the other side, Sarah's Social Experience is higher than average, due to her being in frequently shifting social circumstances in her line of work. With her being interested in interior design, her Topical Experience is also higher than average but significantly lower than Emily's.

7.1.3. Technology A

Technology A is a networked VR solution for which users wear a head-mounted display and use controllers in each hand to interact. Emily is tech-savvy but has not worked with this technology before. Sarah has low Channel Experience. VR provides a very high Interactivity, with voice, hand and head motion being natural extensions of yourself. The System Immersion is high

due to the sensory cues and their fidelity that the hardware can present. The unique System Affordances allow Sarah and Emily to enter a digital version of Sarah's penthouse and arrange different design prototypes of Emily's. They can move and alter the proposed furniture, but also the lighting conditions, times of day and even have an avatar use it. This benefits the Received Information immensely. Both Emily and Sarah are free to build up self-representations in the form of avatars and have the technology display it. However facial expressions and posture are not accurately portrayed. This lessens the Social Presence slightly. While Emily's CL is below average, due to her experience and the naturalness of the medium, Sarah will probably experience moments of confusion and could sometimes struggle to convey information, due to her low Channel Experience. Her Received Information will be somewhat diminished.

7.1.4. Technology B

Technology B is a generic video conferencing solution. Both Sarah and Emily have high Channel Experience due to it being highly relevant to their profession. The Interactivity is constrained compared to the capabilities of the other technology, but Sarah and Emily can exploit the existing capabilities. The System Immersion is limited to the video stream, text, and audio. The System Affordances allow Emily to share different prototype renders from various angles. Both participants can build up self-representation somewhat freely, heavily relying on the camera image to transport their identity. The Received Information on Sarah's end is impacted by the fact that her perspective is 2D and controlled by Emily. And while Emily can react to Sarah's input in limited fashion, it is still an indirection and not all changes are possible on the fly.

7.1.5. Evaluation

The *Social Presence* is slightly higher with technology B than in technology A. Although both technologies do not transmit a complete image of the other person, the information transmitted with technology B appears more natural. The opposite is true for *Received Information*, where both technologies transmit the same digital prototype with a different depth. Here, technology A's Interactivity provides a three-dimensional experience in a responsive virtual environment, which is much more complete. Especially the lacking Interactivity for Sarah disrupts the flow of communication with technology B. The *Cognitive Load* is less when using technology B, but the

difference will become less with Emily continuing to use it for multiple clients. Those clients like Sarah, however, will continue to experience high cognitive load until VR experiences are mainstream and clients already have Channel Experience. Ultimately, the communication situation is better accommodated with the networked VR solution, if both participants can overcome the acclimatization phase where Sarah builds up some Channel Experience.

7.2. Highlighting System Affordances

7.2.1. Preparation

The fictional company SecureID is tasked with providing reliable identification of individuals to online services. Therefore, the transmission of biometric information in combination with legal documents is central to establishing a user's identity. Mark Thompson is a young service worker employed by SecureID. As part of his role, Mark is responsible for accurately verifying the identities of customers. At the age of 22 and after three years with the company, he is tech-savvy and adept at utilizing their toolset. He is detail-oriented and understands the critical service his company provides. Therefore, he also is very security-conscious and respects the measures needed to protect client information. As a digital native Mark is comfortable with everything internet and has developed good media skills, which also enable him to critically scrutinize the processes he is involved in. He understands that the people on the other end just want to be verified, so he tries to be both effective and empathetic. As an online identity verifier, Mark wants to accurately verify his customers', so that they can use online services securely. Aaradhya Anderson is a middle-aged mother of two who is seeking to enable online banking with her credit institution. She wants the convenience and efficiency of online banking but lacks extensive experience with digital technologies. As her bank has shifted from a postal identification system to SecureID, she now goes through their identity verification process. Most importantly she wants to navigate the process smoothly while ensuring the protection of her personal and financial information. She relies on the service provider to provide accurate and easy instructions on what to do. She places her trust in the choice of business partner her credit institution has made and therefore is willing to complete the process through SecureID. As a customer, Aaradhya wants to be verified easily with her credit institution, so that she can securely and easily control her finances online.

7.2.2. Personal Aspects

Mark has very high Social Experience in similar situations, as it has been a central part of his job for three years. Similarly, his Topical Experience is exceptionally high. On the other side, Aaradhya's Social Experience is low, due to her identifying herself online for the first time. With her being new to the entire process, her Topical Experience is also low.

7.2.3. Technology A

Technology A is a networked VR solution. Mark is tech-savvy and knows the technology well. Aaradhya has very low Channel Experience with this technology. Technology A provides a very high Interactivity, with voice, hand and head motion being natural extensions of yourself. The System Immersion is high. The System Affordances of the technology require both participants to be represented through an avatar. They can move and talk, but non-verbal cues are partially transmitted. Both participants can build up self-representations freely and have the technology display it. The Received Information is mostly artificial, with neither seeing facial expressions nor being able to transmit physical items, such as passports or other documents. While Marks' CL is below average, due to his experience and the naturalness of the medium, Sarah will certainly experience confusion and will struggle to prove her identity, both due to her low Channel Experience, but also due to the unsuitable Interactivity.

7.2.4. Technology B

Technology B is a video conferencing-based solution that has been customized by SecureID. Mark is highly experienced with the channel. Aaradhya has low Channel Experience with this technology. The technology provides suitable Interactivity, with both a camera image of each person and of relevant documents. Additionally, text and spoken words can be used to interact. The System Affordances of the software allow Aaradhya to share the data contained on her identity card. Both participants can build up self-representation somewhat freely, heavily relying on the camera image to transport their identity. Both Mark and Aaradhya should experience good Social Presence and Mark should be able to easily verify Aaradhya due to the transmitted image of her person, her physical documents and the data contained on her ID card.

7.2.5. Evaluation

The *Social Presence* is slightly higher with technology B than in technology A. Although both technologies do not transmit a complete image of the other person, the information transmitted with technology B is more natural. However, this is even more important for the *Received Information*, where technology B is much more useful by transmitting a captured representation of reality, rather than a digital environment. The *Cognitive Load* is less when using technology B, and the difference will increase until VR experiences becomes mainstream, as video conferencing is almost ubiquitous. Especially the lack of captured video images holds the VR solution back. Additionally, the unique affordance of accessing the data of the identity card provides an additional marker of authenticity in this process. The scenario is most likely better accommodated with the customized video conferencing solution.

7.3. Highlighting Assymmetry

7.3.1. Preparation

Chun Lee, 32, is a PhD candidate who conducts online courses for students at a university. She is dedicated to providing high-quality education and explaining intricacies of the subject matter. She is both knowledgeable and a great educator, constantly improving and updating her material. Her topic is important to her, and she enjoys sharing her expertise with others. Maintaining an approachable demeanor and encouraging an open learning environment is important to Chun. And while she has a strong research focus and time pressure to publish, she also encourages her students to question and critically analyze her lectures. As an instructor, Chun wants to engage her students and teach them the subject matter, so that they can rely on their education to find a job and do it well. Felix Ruiz is a first-year student majoring in business administration at the same university. He is currently taking a course on operations management practices as part of his degree. While Felix has a general interest in the field of business, he sees his university education as a means to an end and is primarily focused on achieving good grades and eventually securing a job in the industry. Felix tends to be less motivated when it comes to academic pursuits that he perceives as less relevant to his career goals. He is not necessarily disinterested in operations management, but he often struggles to see the practical value of the subject beyond passing exams. As a student, Felix wants to pass the exam with a decent grade, so that he can use his diploma to find a well-paying job.

7.3.2. Personal Aspects

Chun has very high Social Experience and Topical Experience due to her position. On the other side, Felix' Social Experience is average, due to him being a normal university student. As he takes the course for the first time, his Topical Experience is low.

7.3.3. Technology A

Technology A is a generic video conferencing-based solution, where Felix turns off his video and camera. Both Felix and Chun are highly experienced with the channel. The technology provides suitable Interactivity to Chun, transmitting both a camera image of her and her voice. Additionally, she can share her prepared slides, video clips and incorporate real time polls of her students' opinions. Felix on the other hand only has very limited Interactivity available after configuring his Interactivity to exclude voice and video. He can only participate via text chat. Only Chun can build up a relevant self-representation. Felix most likely experiences a good Social Presence if he is actively engaged. He on the other hand has minimal self-representation, evoking hardly any Social Presence. This means Chun is unable to gauge his reaction to her materials, explanations, and demeanor. Also, she is only able to receive very limited information, with her not monitoring the chat closely and Felix having to type out his message. This has an impact on Chun, as she is not receiving the feedback she needs, leading to increased CL. On the other hand, Felix is not getting immediate feedback and Chun will not clarify explanations that did he did not fully understand. This has the potential to lead to further communication errors later, when partial understanding or gaps in understanding become relevant advanced concepts.

7.3.4. Technology B

Now as Technology B regards the same, but with Felix turning on his video and camera. Both Felix and Chun are highly experienced with the channel. The technology provides suitable Interactivity to both participants, transmitting both a camera image and voice. Additionally, she can share her prepared slides, video clips and incorporate real time polls of her students' opinions. Both Chun and Felix can build up a relevant self-representation. Felix most likely experiences decent Social Presence but his Social Presence might be diminished by him not fitting on Chun's screen due to the number of participating students. But his camera image is shown when he talks. This means Chun can gauge the reaction to her materials, explanations, and

demeanor. She gets immediate feedback due to non-verbal communication cues like wrinkled foreheads, nods, or the shaking of heads. This decreases her CL, as she can focus on aspects that are still unclear, having a good idea of what information has been received fully. On the other hand, Felix receives help as soon as he requires it, with Chun having the opportunity to clarify explanations that did he did not fully understand. This should reduce both their CL and increase Felix' Topical Experience, having received accurate information that future concepts build upon.

7.3.5. Evaluation

With technology A, we have analyzed that *Social Presence* is much weaker than with technology B because Felix significantly reduces his Interactivity by disabling parts of it. Likewise, the *Received Information* is worse for Chun, with her struggling to gauge Felix' understanding. This also increases the overall *Cognitive Load* with technology A for both participants. Therefore, the communication situation is most likely better accommodated with the student enabling his camera, where both parties can rely on the Social Presence and a large quantity of different communication cues. Especially the lack of feedback and bi-directional communication hamper the teaching experience. Additionally, the increased Social Presence between Felix' and other students should also provide a more enjoyable learning environment. Together, the three scenarios highlighted how strongly the suitability of the individual technology depends on the specific scenario. Only with suitable personas and a clearly defined scenario can the personal dynamics of a communication situation be structured. Especially the Channel Experience can be observed as a significant hurdle to establishing any new communication technology, even if it is more suitable in the future.

8. Limitations and Conclusion

In this paper, we developed the CoCoTeS Model to enable comparisons between communication technologies and assess their relative suitability. We provide both a theoretical derivation of the model, as well as use case scenarios. By presenting a usage schema (see Figure 4) and illustrating this approach for three different use cases, we provide additional. Additionally, we highlighted how asymmetric situations and System Affordances can be evaluated. By splitting technical and social aspects of communication in our model, we can consider multiple important aspects such as fidelity, usability,

accessibility, but also the social and cultural contexts in which communication takes place. The importance of personal traits becomes immediately obvious to users, due to it filling similar amounts of space in the model as properties of the technology. The possibility that educating users may be more effective than technically revising individual features of the technology used should immediately come to mind. The CoCoTeS therefore provides a uniform basis for describing communication processes and promotes conveying a more holistic perspective. When applying our model, it is important to keep in mind that an overview of the technologies to be compared is required. Due to the expected effort the target group are decision makers in companies, that select the technologies to be purchased and used, since with them both the knowledge, but also cost-benefit ratio of applying the model converge logically. Also, specifying communication is a highly involved endeavor. Weighing smaller differences becomes increasingly difficult, leading the current iteration of the model most equipped to handle larger differences in considered technologies that comparing mostly identical video conferencing systems for example. Additionally, the way we evaluated the CoCoTeS Model is still somehow limited and an empirical evaluation with real decision makers in companies would be a natural next step. Furthermore, economic calculations play no role in our current iteration of the model – while we do touch on incompatibility, we do not provide a risk or cost-benefit assessment as part of the process. These external factors need to be considered on a case-by-case basis, possibly making a better suited communication technology a less practical choice. We also do not consider environmental influences such as privacy concerns, the expectation towards a technology (Nowak and Biocca, 2003) or legal concerns that could influence the communication process. We would expect these to be additional, moderating factors that influence the connection between a person and the System Immersion and Interactivity concepts. Also, we do not consider personality attributes of the individuals in our model. Neither psychological nor physiological aspects are included. In essence, we would expect them to function similarly to experience – affecting the Interactivity and System Immersion. As far as CMC theories go – we have not exhausted all possibilities. Instead, it can be assumed that further arguments for the connections of the components and the extension of the model can be found. A reasonable starting point could be to integrate the not yet considered Media Compensation Theory (Hantula et al., 2011). Our core competency lies strongly in the technological and technology-informed concepts of this model – we call on other specialties to weigh in and improve

the social and psychological aspects.

Our rationale for the CoCoTeS Model as a holistic lens for communication technologies is supported by several established CMC theories and provides a transparent line of reasoning for the suitability of individual technologies. The logical next step for our research is to test the model in practice, which will identify opportunities for advancing the model. For the moment we provide an overarching construct of relationships between established theoretical components. We link up eight major CMC theories and highlight the added value that a VR perspective on digital communication can bring in unifying a set of formerly loosely related characteristics into which technologies have been categorized.

References

, 2011. Psychology of Learning and Motivation. Elsevier.

Abrahamson, E., 1991. Managerial Fads and Fashions: The Diffusion and Rejection of Innovations. Academy of Management Review 16, 586–612.

Aburumman, N., Gillies, M., Ward, J.A., Hamilton, A.F.C., 2022. Nonverbal communication in virtual reality: Nodding as a social signal in virtual interactions. International Journal of Human-Computer Studies 164, 102819. URL: https://www.sciencedirect.com/science/article/pii/S1071581922000489.

Adams, R.B., Albohn, D.N., Kveraga, K., 2017. Social Vision: Applying a Social-Functional Approach to Face and Expression Perception. Current directions in psychological science 26, 243–248.

Alexander Romiszowski, Robin Mason, 2013. Computer-mediated Communication, in: Handbook of Research on Educational Communications and Technology. Routledge, pp. 402–436. URL: https://www.taylorfrancis.com/chapters/edit/10.4324/9781410609519-23/computer-mediated-communication-alexander-romiszowski-robin-mason.

Alice, T., Lengel, L., Thurlow, C., 2004. Computer Mediated Communication Social Interaction and The Internet.

Aranda, G., Vizcaino, A., Cechich, A., Piattini, M., 2006. Technology Selection to Improve Global Collaboration, in: 2006 IEEE International Conference on Global Software Engineering (ICGSE'06), IEEE. pp. 223–232.

Arnold, R., Schneider, A., Lennartz, J., 2020. Interoperability of interpersonal communications services – A consumer perspective. Telecommunications Policy 44, 101927.

Bargh, J.A., McKenna, K.Y.A., Fitzsimons, G.M., 2002. Can You See the Real Me? Activation and Expression of the "True Self" on the Internet. Journal of Social Issues 58, 33–48.

Barnlund, D.C., 1970. A transactional model of communication, in: Sereno, K.K., Mortensen, C.D. (Eds.), Foundations of communication theory. Harper & Row, New York, p. 83.

Becker, J., Holznagel, B., Müller, K., 2021. Interoperability of Messenger Services. Possibilities for a Consumer-Friendly Approach, in: Perspectives on platform regulation, Nomos. pp. 119–144. URL: https://www.nomos-elibrary.de/10.5771/9783748929789-119/interoperability-of-messenger-services-possibilities-for-a-consumer-friendly-ap page=1.

Beukelman, D.R., Light, J.C., 2020. Augmentative & alternative communication: Supporting children and adults with complex communication needs. Fifth edition ed., Brookes Publishing and Paul H. Brookes Publishing Co, Baltimore. URL: https://brookespublishing.com/wp-content/uploads/2020/01/beukelman-first-proofs-excerpt.pdf.

Beyea, D., van der Heide, B., Ewoldsen, D., Eden, A., Meng, J., 2021. Avatar-Based Self-Influence in a Traditional CMC Environment. Journal of Media Psychology .

Biao Zhang, Barry Haddow, Rico Sennrich, 2022. Revisiting End-to-End Speech-to-Text Translation From Scratch. International Conference on Machine Learning , 26193–26205URL: https://proceedings.mlr.press/v162/zhang22i.html.

Biocca, F., Harms, C., Burgoon, J.K., 2003. Toward a More Robust Theory and Measure of Social Presence: Review and Suggested Criteria. Presence: Teleoperators and Virtual Environments 12, 456–480.

Biocca, F., Levy, M.R., 2013. Communication in the Age of Virtual Reality. Routledge. URL: https://www.

taylorfrancis.com/books/mono/10.4324/9781410603128/communication-age-virtual-reality-frank-biocca-mark-levy.

Bourreau, M., Kraemer, J., 2022. Interoperability in Digital Markets. SSRN Electronic Journal .

Bowman, D.A., McMahan, R.P., 2007. Virtual Reality: How Much Immersion Is Enough? Computer 40, 36–43.

Bredikhina, L., 2020. Designing identity in VTuber Era. URL: https://www.researchgate.net/profile/liudmila-bredikhina/publication/363587218_designing_identity_in_vtuber_era.

Brooks, F.P., 1999. What's real about virtual reality? IEEE Computer Graphics and Applications 19, 16–27.

Brünken, R., Plass, J.L., Moreno, R., 2010. Current Issues and Open Questions in Cognitive Load Research, in: Cognitive Load Theory. Cambridge University Press, pp. 253–272.

Buehling, K., 2023. Message Deletion on Telegram: Affected Data Types and Implications for Computational Analysis. Communication Methods and Measures , 1–23.

Burbury, K., Wong, Z.W., Yip, D., Thomas, H., Brooks, P., Gilham, L., Piper, A., Solo, I., Underhill, C., 2021. Telehealth in cancer care: during and beyond the COVID-19 pandemic. Internal medicine journal 51, 125–133.

Calvert, J., 2005. Distance Education at the Crossroads. Distance Education 26, 227–238.

Campbell, A.G., Holz, T., Cosgrove, J., Harlick, M., O'Sullivan, T., 2020. Uses of Virtual Reality for Communication in Financial Services: A Case Study on Comparing Different Telepresence Interfaces: Virtual Reality Compared to Video Conferencing, Springer, Cham. pp. 463–481. URL: https://link.springer.com/chapter/10.1007/978-3-030-12388-8_33.

Carlson, J.R., Zmud, R.W., 1999. Channel expansion theory and the experiential nature of media richness perceptions. Academy of Management Journal 42, 153–170.

Carr, C.T., 2020. CMC Is Dead, Long Live CMC!: Situating Computer-Mediated Communication Scholarship Beyond the Digital Age. Journal of Computer-Mediated Communication 25, 9–22.

Castro, R., Vaca, C., 2017. National Leaders' Twitter Speech to Infer Political Leaning and Election Results in 2015 Venezuelan Parliamentary Elections, in: 2017 IEEE International Conference on Data Mining Workshops (ICDMW), IEEE.

Cennamo, C., Kretschmer, T., Constantinides, P., Alaimo, C., Santaló, J., 2023. Digital Platforms Regulation: An Innovation-Centric View of the EU's Digital Markets Act. Journal of European Competition Law & Practice 14, 44–51.

Chandler, P., Sweller, J., 1991. Cognitive Load Theory and the Format of Instruction. Cognition and Instruction 8, 293–332.

Chang, Y.n., Lim, Y.k., Stolterman, E., 2008. Personas: From Theory to Practices, in: Proceedings of the 5th Nordic conference on Human-computer interaction: building bridges, ACM. pp. 439–442.

Cheok, A.D., Karunanayaka, K., 2018. Virtual Taste and Smell Technologies for Multisensory Internet and Virtual Reality. Springer International Publishing, Cham.

Clement, E., Lejeune, C., Coeurderoy, R., 2017. Web conferencing solutions on a global scale: challenges for software vendors, strategic partners and clients .

Cohn, M., 2004. User Stories Applied: For Agile Software Development. Addison-Wesley Professional.

Cooper, A., 2004. Inmates Are Running the Asylum, the: Why High-Tech Products Drive Us Crazy and How to Restore the Sanity. 2nd edition ed., Sams.

Correia, A.P., Liu, C., Xu, F., 2020. Evaluating videoconferencing systems for the quality of the educational experience. Distance Education 41, 429–452.

Daft, R.L., Lengel, R.H., 1983. Information Richness. A New Approach to Managerial Behavior and Organization Design. Defense Technical Information Center, Fort Belvoir, VA.

Daft, R.L., Lengel, R.H., Trevino, L.K., 1987. Message equivocality, media selection, and manager performance: Implications for information systems. MIS Quarterly , 355–366.

Dhillon, G., Backhouse, J., 2001. Current directions in IS security research: towards socio-organizational perspectives. Information Systems Journal 11, 127–153.

Diener, E., 1980. Deindividuation: The absence of self-awareness and self-regulation in group members. The psychology of group influence. URL: https://scholar.google.com/citations?user=_xr5tl8aaaaj&hl=en&oi=sra.

Dozio, N., Maggioni, E., Pittera, D., Gallace, A., Obrist, M., 2021. May I Smell Your Attention: Exploration of Smell and Sound for Visuospatial Attention in Virtual Reality. Frontiers in Psychology 12, 671470. URL: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.671470/full.

D'Urso, S.C., Rains, S.A., 2008. Examining the scope of channel expansion: A test of channel expansion theory with new and traditional communication media. Management Communication Quarterly 21, 486–507.

Ellis, R.E., McClintock, A., 1990. If You Take My Meaning: Theory into Practice in Human Communication.

Fernández-Batanero, J.M., Montenegro-Rueda, M., Fernández-Cerero, J., Tadeu, P., 2022. Online education in higher education: emerging solutions in crisis times. Heliyon 8, e10139.

Finnegan, R., 2005. Communicating: The multiple modes of human interconnection. 2 ed., Routledge, London. URL: https://api.taylorfrancis.com/content/books/mono/download?identifiername=doi&identifiervalue=10.4324/9780203994009&type=googlepdf.

Fiol, C.M., O'Connor, E.J., 2003. Waking Up! Mindfulness in the Face of Bandwagons. Academy of Management Review 28, 54–70.

Freeth, M., Foulsham, T., Kingstone, A., 2013. What affects social attention? Social presence, eye contact and autistic traits. PloS one 8, e53286.

Gangneux, J., 2019. Rethinking social media for qualitative research: The use of Facebook Activity Logs and Search History in interview settings. The Sociological Review 67, 1249–1264.

Gill, M.M., 1994. Accent and stereotypes: Their effect on perceptions of teachers and lecture comprehension. Journal of Applied Communication Research 22, 348–361.

Haldane, M., 2007. Interactivity and the digital whiteboard: weaving the fabric of learning. Learning, Media and Technology 32, 257–270.

Han, E., Miller, M.R., Ram, N., Nowak, K.L., Bailenson, J.N., 2022. Understanding Group Behavior in Virtual Reality: A Large-Scale, Longitudinal Study in the Metaverse.

Hantula, D.A., Kock, N., D'Arcy, J.P., DeRosa, D.M., 2011. Media Compensation Theory: A Darwinian Perspective on Adaptation to Electronic Communication and Collaboration, in: Saad, G. (Ed.), Evolutionary Psychology in the Business Sciences. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 339–363.

Harley, D., Verni, A., Willis, M., Ng, A., Bozzo, L., Mazalek, A., 2018. Sensory VR: Smelling, touching, and eating virtual reality, in: Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction, ACM.

Hauber, J., Regenbrecht, H., Hills, A., Cockburn, A., Billinghurst, M., 2005. Social presence in two- and three-dimensional videoconferencing. University of Canterbury. Computer Science and Software Engineering and University of Canterbury. Human Interface Technology Laboratory. URL: http://ir.canterbury.ac.nz/handle/10092/352.

Hiltz, S.R., Johnson, K., Agle, G., 1978. Replicating Bales Problem Solving Experiments on a Computerized Conference: A Pilot Study .

Homer, B.D., Plass, J.L., Blake, L., 2008. The effects of video on cognitive load and social presence in multimedia-learning. Computers in Human Behavior 24, 786–797. URL: https://www.sciencedirect.com/science/article/pii/S0747563207000544.

Jasperson, Carter, Zmud, 2005. A Comprehensive Conceptualization of Post-Adoptive Behaviors Associated with Information Technology Enabled Work Systems. MIS Quarterly 29, 525.

Javornik, A., Marder, B., Barhorst, J.B., McLean, G., Rogers, Y., Marshall, P., Warlop, L., 2022. 'What lies behind the filter?' Uncovering the motivations for using augmented reality (AR) face filters on social media and their effect on well-being. Computers in Human Behavior 128, 107126.

Jiang, L.C., Bazarova, N.N., Hancock, J.T., 2011. The disclosure–intimacy link in computer-mediated communication: An attributional extension of the hyperpersonal model. Human communication research 37, 58–77.

Jones, A., Lang, M., Fyffe, G., Yu, X., Busch, J., McDowall, I., Bolas, M., Debevec, P., 2009. Achieving eye contact in a one-to-many 3D video teleconferencing system. ACM Transactions on Graphics 28, 1–8.

Jones, S., 1995. CyberSociety 2.0 [electronic resource] : revisiting computer-mediated communication and community: Revisiting Computer-Mediated Community and Technology. SAGE.

de Jong, T., 2010. Cognitive load theory, educational research, and instructional design: some food for thought. Instructional Science 38, 105–134.

Kalla, H.K., 2005. Integrated internal communications: a multidisciplinary perspective. Corporate Communications: An International Journal 10, 302–314.

Kalyuga, S., Ayres, P., Chandler, P., Sweller, J., 2003. The Expertise Reversal Effect. Educational Psychologist 38, 23–31.

Kaur, N., Singh, P., 2023. Conventional and contemporary approaches used in text to speech synthesis: a review. Artificial Intelligence Review 56, 5837–5880. URL: https://link.springer.com/article/10.1007/s10462-022-10315-0.

Kaye, L.K., Rousaki, A., Joyner, L.C., Barrett, L.A., Orchard, L.J., 2022. The Online Behaviour Taxonomy: A conceptual framework to understand behaviour in computer-mediated communication. Computers in Human Behavior 137, 107443.

Kelman, H.C., 1958. Compliance, identification, and internalization three processes of attitude change. Journal of conflict resolution 2, 51–60.

Kim, H.I., Kim, T., Song, E., Oh, S.Y., Kim, D., Woo, W., 2021. Multi-scale Mixed Reality Collaboration for Digital Twin, in: 2021 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct), IEEE.

Kock, N., 2004. The psychobiological model: Towards a new theory of computer-mediated communication based on Darwinian evolution. Organization Science 15, 327–348.

Kock, N., 2005. Media richness or media naturalness? The evolution of our biological communication apparatus and its influence on our behavior toward e-communication tools. IEEE transactions on professional communication 48, 117–130.

Kock, N., 2007. Media naturalness and compensatory encoding: The burden of electronic media obstacles is on senders. Decision Support Systems 44, 175–187.

Kwon, J.H., Powell, J., Chalmers, A., 2013. How level of realism influences anxiety in virtual reality environments for a job interview. International Journal of Human-Computer Studies 71, 978–987. URL: https://www.sciencedirect.com/science/article/pii/S1071581913000876.

Laitinen, K., Valo, M., 2018. Meanings of communication technology in virtual team meetings: Framing technology-related interaction. International Journal of Human-Computer Studies 111, 12–22. URL: https://www.sciencedirect.com/science/article/pii/S1071581917301507.

Lea, M., Spears, R., 1992. Paralanguage and social perception in computer–mediated communication. Journal of Organizational Computing 2, 321–341.

Lee, A., Gong, H., Duquenne, P.A., Schwenk, H., Chen, P.J., Wang, C., Popuri, S., Adi, Y., Pino, J., Gu, J., Hsu, W.N., 2022. Textless Speech-to-Speech Translation on Real Data.

Lee, C.E.C., 2010. Face-to-face versus computer-mediated communication: Exploring employees' preference of effective employee communication channel.

Lee, K.M., 2004. Presence, Explicated. Communication Theory 14, 27–50.

Lee, K.M., Nass, C., 2005. Social-Psychological Origins of Feelings of Presence: Creating Social Presence With Machine-Generated Voices. Media Psychology 7, 31–45.

Lee, S., Pitesa, M., Pillutla, M., Thau, S., 2015. When beauty helps and when it hurts: An organizational context model of attractiveness discrimination in selection decisions. Organizational Behavior and Human Decision Processes 128, 15–28.

Lieux, M., Sabottke, C., Schachner, E.R., Pirtle, C., Danrad, R., Spieler, B., 2021. Online conferencing software in radiology: Recent trends and utility. Clinical imaging 76, 116–122.

Lucassen, G., Dalpiaz, F., van der Werf, J.M.E.M., Brinkkemper, S., 2016. The Use and Effectiveness of User Stories in Practice, Springer, Cham. pp. 205–222. URL: https://link.springer.com/chapter/10.1007/978-3-319-30282-9_14.

Maras, S., 2000. Beyond the transmission model: Shannon, Weaver, and the critique of sender/message/receiver. Australian Journal of Communication 27, 123–142. URL: https://search.informit.org/doi/pdf/10.3316/ielapa.200107346.

Mayer, R., Mayer, R.E., 2005. The Cambridge Handbook of Multimedia Learning. Cambridge University Press.

Miller, G.A., 1956. The magical number seven, plus or minus two: Some limits on our capacity for processing information. Psychological review 63, 81.

Mora-Jimenez, L.D., Ramírez-Benavides, K., Quesada, L., Lopez, G., Guerrero, L.A., 2022. User Experience in Communication and Collaboration Platforms: A Comparative Study Including Discord, Microsoft Teams, and Zoom, in: Rocha, Á., Ferrás, C., Méndez Porras, A., Jimenez Delgado, E.

(Eds.), Information Technology and Systems. Springer International Publishing, Cham. volume 414 of *Lecture Notes in Networks and Systems*, pp. 52–61.

Mütterlein, J., 2018. The Three Pillars of Virtual Reality? Investigating the Roles of Immersion, Presence, and Interactivity. URL: https://scholarspace.manoa.hawaii.edu/handle/10125/50061.

Mütterlein, J., Hess, T., 2017. Immersion, presence, interactivity: Towards a joint understanding of factors influencing virtual reality acceptance and use. URL: https://core.ac.uk/download/pdf/301371675.pdf.

Naughton, E.J., 1992. Is Cyberspace a Public Forum-Computer Bulletin Boards, Free Speech, and State Action. URL: https://heinonline.org/hol-cgi-bin/get_pdf.cgi?handle=hein.journals/glj81ÂğionÂ=27.

Nilsson, N.C., Nordahl, R., Serafin, S., 2016. Immersion Revisited: A review of existing definitions of immersion and their relation to different theories of presence. Human Technology 12, 108–134.

Nowak, K.L., Biocca, F., 2003. The Effect of the Agency and Anthropomorphism on Users' Sense of Telepresence, Copresence, and Social Presence in Virtual Environments. Presence: Teleoperators and Virtual Environments 12, 481–494.

Nowak, K.L., Fox, J., 2018. Avatars and computer-mediated communication: A review of the definitions, uses, and effects of digital representations on communication. Review of Communication Research 6, 30–53. URL: https://www.ssoar.info/ssoar/handle/document/55777.

Nowak, K.L., Watt, J., Walther, J.B., 2009. Computer mediated teamwork and the efficiency framework: Exploring the influence of synchrony and cues on media satisfaction and outcome success. Computers in Human Behavior 25, 1108–1119.

Office of Communications, 2006. Access Services Survey 2005: Technical Report, Marked-up Questionnaires and Computer Tables. URL: https://www.ofcom.org.uk/__data/assets/pdf_file/0026/40985/survey.pdf.

Paas, F.G.W.C., 1992. Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive-load approach. Journal of Educational Psychology 84, 429–434.

Pan, X., Hamilton, A.F.d.C., 2018. Why and how to use virtual reality to study human social interaction: The challenges of exploring a new research landscape. British journal of psychology (London, England : 1953) 109, 395–417.

Pfeiffer, J., Pfeiffer, T., Meißner, M., Weiß, E., 2020. Eye-Tracking-Based Classification of Information Search Behavior Using Machine Learning: Evidence from Experiments in Physical Shops and Virtual Reality Shopping Environments. Information Systems Research 31, 675–691.

Postmes, T., Spears, R., 1998. Deindividuation and antinormative behavior: A meta-analysis. Psychological bulletin 123, 238.

Puhl, R.M., Andreyeva, T., Brownell, K.D., 2008. Perceptions of weight discrimination: prevalence and comparison to race and gender discrimination in America. International Journal of Obesity 32, 992–1000. URL: https://www.nature.com/articles/ijo200822.

Ritchie, D., 1986. Shannon and Weaver: Unravelling the paradox of information 13, 278–298. URL: https://journals.sagepub.com/doi/pdf/10.1177/009365086013002007?casa_token=b5ii1chjjfwaaaaa:7ehf-gc_8jc9gombzecme_z7bgsni9tefvbaetbpzvyd3ixvtorzlsqvu_gzwbitc-jwkvsmavqp0a.

Rosenberg, I.B., 2009. Height Discrimination in Employment. SSRN Electronic Journal .

Roy, A.B., 2019. Translation, Sentiment and Voices: A Computational Model to Translate and Analyse Voices from Real-Time Video Calling.

Ryan, M.L., 1999. Immersion vs. Interactivity: Virtual Reality and Literary Theory. SubStance 28, 110–137. URL: https://muse.jhu.edu/pub/19/article/32231/summary.

Sabah Al-Fedaghi, 2012. A Conceptual Foundation for the Shannon-Weaver Model of Communication. International Journal of Soft Computing 7, 12–19. URL: https://www.researchgate.net/

profile/sabah-al-fedaghi/publication/272964534_a_conceptual_foundation_for_the_shannon-weaver_model_of_communication.

Salancik, G.R., Pfeffer, J., 1978. A social information processing approach to job attitudes and task design. Administrative science quarterly , 224–253.

Salisbury, W.D., Carte, T.A., Chidambaram, L., 2006. Cohesion in Virtual Teams: Validating the Perceived Cohesion Scale in a Distributed Setting. SIGMIS Database 37, 147–155.

Seeger, A.M., Pfeiffer, J., Heinzl, A., 2021. Texting with Humanlike Conversational Agents: Designing for Anthropomorphism. Journal of the Association for Information Systems 22, 931–967.

Sehra, S., Maghu, S., Bhardwawaj, A., 2014. Comparative analysis of E-learning and distance learning techniques.

Serrano, B., Baños, R.M., Botella, C., 2016. Virtual reality and stimulation of touch and smell for inducing relaxation: A randomized controlled trial. Computers in Human Behavior 55, 1–8.

Shannon, C.E., 1948. A Mathematical Theory of Communication. Bell System Technical Journal 27, 379–423.

Shannon, C.E., 1949. Communication in the presence of noise. Proceedings of the IRE 37, 10–21.

Shehabuddeen, N., Probert, D., Phaal, R., 2006. From theory to practice: challenges in operationalising a technology selection framework. Technovation 26, 324–335.

Short, J., Williams, E., Christie, B., 1976. The social psychology of telecommunications. Wiley, London.

Sjølie, E., Espenes, T.C., Buø, R., 2022. Social interaction and agency in self-organizing student teams during their transition from face-to-face to online learning. Computers & Education 189, 104580.

Slater, M., 2003. A note on presence terminology. volume 3. Presence connect. URL: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.800.3452&rep=rep1&type=pdf.

Slater, M., Sanchez-Vives, M.V., 2016. Enhancing Our Lives with Immersive Virtual Reality. Frontiers in Robotics and AI 3, 236866. URL: https://www.frontiersin.org/articles/10.3389/frobt.2016.00074/full.

Slater, M., Wilbur, S., 1997. A Framework for Immersive Virtual Environments (FIVE): Speculations on the Role of Presence in Virtual Environments. Presence: Teleoperators and Virtual Environments 6, 603–616.

Smith, H.J., Neff, M., 2018. Communication behavior in embodied virtual reality, in: Proceedings of the 2018 CHI conference on human factors in computing systems, pp. 1–12.

Solska, D., 2022. Traversing the Metaverse: the new frontiers for computer-mediated communication and natural language processing. Forum Filologiczne Ateneum , 27–38.

Steuer, J., Biocca, F., Levy, M.R., et al., 1995. Defining virtual reality: Dimensions determining telepresence. Communication in the age of virtual reality 33, 37–39.

Suh, Lee, 2005. The Effects of Virtual Reality on Consumer Learning: An Empirical Investigation. MIS Quarterly 29, 673.

Sun, H., 2013. A Longitudinal Study of Herd Behavior in the Adoption and Continued Use of Technology. MIS Quarterly 37, 1013–1041.

Sun, H., Fang, Y., Zou, H., 2016. Choosing a Fit Technology: Understanding Mindfulness in Technology Adoption and Continuance. Journal of the Association for Information Systems 17, 377–412.

Sweller, J., 2011. Cognitive Load Theory, in: Psychology of Learning and Motivation. Elsevier, pp. 37–76.

Sweller, J., Cooper, G.A., 1985. The Use of Worked Examples as a Substitute for Problem Solving in Learning Algebra. Cognition and Instruction 2, 59–89.

Sweller, J., van Merriënboer, J.J.G., Paas, F., 2019. Cognitive Architecture and Instructional Design: 20 Years Later. Educational Psychology Review 31, 261–292. URL: https://link.springer.com/article/10.1007/s10648-019-09465-5.

Tan, W.s., Liu, D., Bishu, R., 2009. Web evaluation: Heuristic evaluation vs. user testing. International Journal of Industrial Ergonomics 39, 621–627.

Tingling, P., Parent, M., 2004. An exploration of enterprise technology selection and evaluation. The Journal of Strategic Information Systems 13, 329–354.

Toan, P.N., Dang, T.T., Le Hong, T.T., 2022. Evaluating Video Conferencing Software for Remote Working Using Two-Stage Grey MCDM: A Case Study from Vietnam. Mathematics 10, 946. URL: `https://www.mdpi.com/1544628`.

van Brakel, V., Barreda-Ángeles, M., Hartmann, T., 2023. Feelings of presence and perceived social support in social virtual reality platforms. Computers in Human Behavior 139, 107523.

Walther, J.B., 1992. Interpersonal Effects in Computer-Mediated Interaction: A Relational Perspective. Communication Research 19, 52–90.

Walther, J.B., 1993. Impression development in computer-mediated interaction. Western Journal of Communication (includes Communication Reports) 57, 381–398.

Walther, J.B., 1996. Computer-Mediated Communication: Impersonal, Interpersonal, and Hyperpersonal Interaction. Communication Research 23, 3–43.

Walther, J.B., 2011. Theories of computer-mediated communication and interpersonal relations. The handbook of interpersonal communication 4, 443–479.

Walther, J.B., Liang, Y.J., DeAndrea, D.C., Tong, S.T., Carr, C.T., Spottswood, E.L., Amichai-Hamburger, Y., 2011. The Effect of Feedback on Identity Shift in Computer-Mediated Communication. Media Psychology 14, 1–26.

Walther, J.B., Parks, M.R., 2002. Cues filtered out, cues filtered in: Computer-mediated communication and relationships. Handbook of interpersonal communication 3, 529–563.

Walther, J.B., van der Heide, B., Ramirez, A., Burgoon, J.K., Peña, J., 2015. Interpersonal and Hyperpersonal Dimensions of Computer–Mediated Communication, in: Sundar, S.S. (Ed.), The handbook of the psychology of communication technology. John Wiley & Sons, New York, NY. volume 1 of *Wiley online library*, pp. 1–22.

Wang, E., Caldwell, B., 2002. An Empirical Study of Usability Testing: Heuristic Evaluation Vs. User Testing. Proceedings of the Human Factors and Ergonomics Society Annual Meeting 46, 774–778.

Watzlawick, P., Bavelas, J.B., Jackson, D.D., 1967. Pragmatics of Human Communication: A Study of Interactional Patterns, Pathologies and Paradoxes. W. W. Norton & Company, New York.

Xi, N., Hamari, J., 2021. Shopping in virtual reality: A literature review and future agenda. Journal of Business Research 134, 37–58.

Yan, S., Choo, K.K.R., Le-Khac, N.A., 2022. Signal Instant Messenger Forensics, in: A Practical Hands-on Approach to Database Forensics. Springer, Cham, pp. 27–92. URL: https://link.springer.com/chapter/10.1007/978-3-031-16127-8_3.

Zamanifard, S., Freeman, G., 2023. A Surprise Birthday Party in VR: Leveraging Social Virtual Reality to Maintain Existing Close Ties over Distance, Springer, Cham. pp. 268–285. URL: https://link.springer.com/chapter/10.1007/978-3-031-28032-0_23.