



# Empowering Interactions: Integrating Self-Determination Theory into Companion Technology Design

DISSERTATION

submitted in partial fulfillment of the requirements for the degree of

**Doktorin der Technischen Wissenschaften**

by

**Ambika Shahu, MSc**

Registration Number 12128325

to the Faculty of Informatics

at the TU Wien

Advisor: Univ.Prof.Dr. Florian Michahelles

The dissertation has been reviewed by:

---

Prof. Dr. Florian Alt

---

Prof. Dr. Stefan Schneegass

Vienna, April 22, 2025

---

Ambika Shahu



# Erklärung zur Verfassung der Arbeit

Ambika Shahu, MSc

Hiermit erkläre ich, dass ich diese Arbeit selbständig verfasst habe, dass ich die verwendeten Quellen und Hilfsmittel vollständig angegeben habe und dass ich die Stellen der Arbeit – einschließlich Tabellen, Karten und Abbildungen –, die anderen Werken oder dem Internet im Wortlaut oder dem Sinn nach entnommen sind, auf jeden Fall unter Angabe der Quelle als Entlehnung kenntlich gemacht habe.

Ich erkläre weiters, dass ich mich generativer KI-Tools lediglich als Hilfsmittel bedient habe und in der vorliegenden Arbeit mein gestalterischer Einfluss überwiegt. Im Anhang „Übersicht verwendeter Hilfsmittel“ habe ich alle generativen KI-Tools gelistet, die verwendet wurden, und angegeben, wo und wie sie verwendet wurden. Für Textpassagen, die ohne substantielle Änderungen übernommen wurden, haben ich jeweils die von mir formulierten Eingaben (Prompts) und die verwendete IT- Anwendung mit ihrem Produktnamen und Versionsnummer/Datum angegeben.

Wien, 22. April 2025

---

Ambika Shahu



# Acknowledgements

First and foremost, I would like to express my sincere gratitude to my supervisor, Prof. Florian Michahelles. His office door was always open whenever I faced difficulties or had questions regarding my research and writing. He provided valuable support throughout this journey. Additionally, I am thankful for his support in enabling me to attend numerous conferences, which allowed me to showcase our research, network, and connect with peers who share similar research interests. I am thankful to my external reviewers, Prof. Florian Alt and Prof. Stefan Schneegass, for their thorough and insightful review of this dissertation. Their detailed comments and constructive suggestions significantly helped me improve the clarity, coherence, and overall quality of this work, making it more comprehensive. I am deeply grateful to my other mentors, Prof. Hilda Tellioglu, Prof. Philipp Wintersberger, Prof. Manuela Waldner, Prof. Katta Spiel, and Prof. Geraldine Fitzpatrick, for their invaluable guidance throughout process. Their technical support, advice on time and stress management, and fresh perspectives enriched both my research and my personal growth. I am heartfully grateful to my fellow Ph.D. student, Khaled Kassem, for supporting me every step of the way, through the highs and the lows. Thank you for always listening, offering support, and being there whenever I needed you. You have been the best Ph.D. companion one could hope for. Many thanks to all my peers and friends Florian Wolling, Ioana Klammer, Yu Wang, Sonja Dorfbauer, Simone Risslegger, Kevin Blasiak, David Kostolani, Lukas Lehner, Silvia-Kay Kender and Naemi Luckner for their administrative and technical support, for creating a welcoming and friendly environment, for always being there to listen, and for bringing kindness and good energy into my daily work life. I would like to thank Sarah Faltaous for her generous support during the writing process, especially for taking the time to review my dissertation structure and sharing valuable tips, tricks and guidance.

I would like to thank all the students who supported me throughout this journey, particularly the bachelor's and master's students who contributed to my empirical work. Your technical assistance helped bring the research artifacts to life, and your support in running the user studies was deeply appreciated. My friends Srishti Dang, Siddharth Mehrotra, Nikita Sharma, Arunima Ved, Priyanka Sharma, and Ivy Rose Sebastian who were always there for me not just in my personal life, but also as a source of steady professional support. I am also indebted to my fitness instructor, Ramona Buta, whose workout routines ensured I had just the right dose of endorphins to stay focused. Finally, I would like to express my heartfelt gratitude to my family, my boyfriend-turned-husband

Jakob Ecker, my sister Anamika Shahu, my parents Kiran and Rajendra Shahu, my in-laws Eva and Gerhard Ecker, my sister-in-law Gudrun Ecker, and my nieces Hanna and Lena Oswald, for their unwavering support and constant encouragement throughout my years of study and the writing of this dissertation. Their love, patience, comforting homemade meals, and belief in me carried me through this journey and made it all possible. A special thanks also goes to my furry companions, Mietzi the cat and Jilli the dog, for keeping me company while I wrote and for bringing small moments of joy to long days of work. Vienna has been truly special, it has given me unforgettable experiences, lifelong friends, a loving partner, and a family. They say it takes a village to complete a PhD, and this journey, both the research and the writing, was made possible through the collective support, encouragement, and kindness of so many people around me. And last but not least, thanks to ChatGPT-4o for assisting me with writing, revisions and adjustments throughout the writing process. No original content was generated, GPT was only used for rewriting, grammar, and sentence structure correction.

# Abstract

Virtual assistants like Alexa, Siri, and AI chatbots are widely used for managing routine tasks but are often seen as tools rather than companions. These systems typically do not support users' basic psychological needs, which limits engagement. This research, grounded in Self-Determination Theory (SDT), explores how digital companions can be designed to support autonomy, competence, and relatedness. The work investigates: (a) how companion systems can empower users by meeting psychological needs, (b) which features are perceived as companion traits, and (c) what design guidelines can help build systems that support user well-being. Using a mixed-methods approach, we evaluate proactive and reactive companion systems across case studies in training and skill building, information access, and digital well-being. Proactive systems like AR/VR companions and muscle stimulation feedback supported learning and collaboration, while reactive systems like a lockable phone box fostered user control and self-reflection. Autonomy is reinforced through clear opt-out mechanisms, adjustable boundaries, and non-intrusive nudges. Competence is supported through tailored feedback, repeatable task structures, and physical guidance. Relatedness is enhanced through dialogue, social accountability, and shared narratives. The dissertation provides future system designers and researchers with actionable guidelines for the design of companion technologies based on empirical research. Companion technologies should be adaptable, unobtrusive, and responsive to diverse user preferences for meaningful interaction. It contributes to the understanding of how technologies can act as great partners, addressing not only functional needs but also psychological well-being. It also calls for further research into long-term user interactions, cultural differences in technology use, and the integration of AI capabilities.



# Contents

<b>Abstract</b>	<b>vii</b>
<b>Contents</b>	<b>ix</b>
<b>I Introduction &amp; Background</b>	<b>1</b>
<b>1 Introduction</b>	<b>3</b>
1.1 Research Questions . . . . .	7
1.2 Methodology . . . . .	7
1.3 Research Contribution . . . . .	9
1.4 Dissertation Outline . . . . .	11
<b>2 Background</b>	<b>15</b>
2.1 Proactive and Reactive Companion Technology . . . . .	15
2.2 Psychological Needs in Companion Technology Design . . . . .	17
2.3 Interaction Modalities in Companion Systems . . . . .	19
<b>II Proactive Companions</b>	<b>23</b>
<b>3 Professional Training and Work Safety Companion</b>	<b>25</b>
3.1 Professional Training with Single-User VR Companion . . . . .	25
3.2 Skillab Companion . . . . .	48
3.3 Teleoperation Companion . . . . .	65
3.4 Acceptance of EMS . . . . .	73
<b>4 Proactive Digital Detox Companion</b>	<b>93</b>
4.1 Nudgit Companion . . . . .	93
4.2 Watchful Detox Companion . . . . .	101
	 ix

<b>III</b>	<b>Reactive Companions</b>	<b>127</b>
<b>5</b>	<b>Informational Companion</b>	<b>129</b>
5.1	MapGPT Companion . . . . .	129
5.2	Carbon Rebellion Companion . . . . .	147
<b>6</b>	<b>Mindful Box Companion</b>	<b>175</b>
6.1	Related Work . . . . .	176
6.2	The Mindful Box Companion . . . . .	177
6.3	Mixed Method User Study . . . . .	182
6.4	Results . . . . .	183
6.5	Conclusion . . . . .	186
<b>IV</b>	<b>Contributions</b>	<b>189</b>
<b>7</b>	<b>Results and Discussion</b>	<b>191</b>
7.1	Findings on Autonomy, Competence, and Relatedness . . . . .	191
7.2	Defining Characteristics of Companion Technologies . . . . .	196
7.3	Guidelines Summerized . . . . .	199
7.4	Discussion . . . . .	200
<b>8</b>	<b>Conclusion</b>	<b>203</b>
	<b>List of Figures</b>	<b>207</b>
	<b>List of Tables</b>	<b>209</b>
	<b>Bibliography</b>	<b>211</b>
<b>A</b>	<b>Supporting Documents</b>	<b>259</b>
A.1	Example Interview Guide - Watchful Detox Companion . . . . .	259
A.2	Example Consent Form - Skillab Companion . . . . .	260
A.3	Use of AI Tools . . . . .	262

# Part I

## Introduction & Background



# CHAPTER 1

## Introduction

The desire for companionship is a fundamental aspect of human nature. The necessity for companionship is not merely a matter of survival, rather, it is an essential factor in the emotional and psychological well-being of individuals. As human society evolved, the concept of companionship manifested in various forms, including friendship, family relationships, romantic relationships, and spiritual connections. Literary, religious, and philosophical discourses have articulated their perspectives on the importance of meaningful companionship. An example of this can be observed in the religious text of the Bhagavad Gita, which dates back over two thousand years. In this text, Krishna acts as Arjuna's charioteer, friend, and spiritual guide and demonstrates how the concept of true companionship is grounded in the provision of support, guidance, and trust.

In the 21st century, the concept of companionship has been transformed. The rise of technology has undeniably expanded the domain of companionship to encompass novel forms of interaction. Virtual assistants like Alexa and Siri, AI-powered chatbots, and social robots are just a few examples of this. There was a notable increase in digital engagement among consumers in 2023, with a 6.5% surge observed in comparison to the previous year <sup>1</sup>. Even the smartphone is perceived as a companion, often representing one of the strongest and longest relationships individuals have with technology today [CBM<sup>+</sup>19]. In the period between 2022 and 2024, global usage of voice assistants saw a considerable increase, with the number of digital voice assistants deployed in use growing from 4.4 million to 8.4 billion over the course of two years <sup>2</sup>. It is increasingly common for people to live with a smart speaker, and there is a growing tendency among some to criticize other users for not treating the device with kindness [SSFH18]. These assistants are particularly adept at assisting individuals in the management of their daily routines, including the setting of reminders, playing music, making calls, alarms,

<sup>1</sup><https://www.pymnts.com/connectedeconomy/2023/consumers-digital-engagement-grew-6-5-as-network-effect-kicks-in/> –Accessed Dec 2024

<sup>2</sup><https://www.astuteanalytica.com/industry-report/voice-assistant-market> –Accessed Dec 2024

and calendar events, controlling smart home devices, and answering factual queries by accessing internet-based information. They facilitate the completion of tasks such as the provision of weather updates or news briefings, thereby offering convenience with minimal effort. These companions have not only affected the way people live but also the way people work by assisting people not only in personal but also in professional daily tasks. Assistants like Microsoft Cortana and Slackbot streamline routine tasks, boosting productivity. They are capable of managing calendars, sending reminders, automating workflows, and providing quick access to relevant information. They can provide users with a sense of companionship through their consistent presence and ability to perform helpful tasks on demand.

Digital innovation in industry and the new ways of human-machine interaction are creating proactive machines that are becoming more than just basic tools, they are becoming smart, integrated companions [RB02, KHY<sup>+</sup>19]. Digital assistants are becoming increasingly prevalent in the workplace, assisting with manual tasks (e.g., industrial robots) and cognitive processes, such as those involved in software development. Also, the concept of Robot Companions has emerged as a paradigm in the field of cognitive robotics [ARARU<sup>+</sup>11, DWK<sup>+</sup>05, MEG<sup>+</sup>04]. These assistant systems can now mimic human communication patterns through advancements in natural language processing (NLP) and are capable of responding in conversational, human-like ways. As knowledge workers are confronted with an ever-increasing volume of information on a daily basis, there is a growing necessity to develop companion technologies that can alleviate the burden of information overload and facilitate the process of sense-making [GF16]. Companion technologies have the potential to enhance the manner in which users procure information, thereby contributing to enhanced efficiency and well-being amongst users, for example, IBM's Watson Health assists doctors by quickly analyzing vast amounts of medical literature and patient data to provide diagnostic recommendations [AM17]. Consequently, such systems may be conceived of as cooperative partners [Gru18] that interact with the human knowledge worker in order to address the increasing complexity of organizational and administrative matters [ME14] (e.g. the need for constant availability).

The term companion has been around for almost two decades now [BB14], which leads us to think precisely about *what constitutes a "digital companion."* There have been several research efforts aimed at defining and conceptualizing digital companion systems [PFL19, NCB18, Say20]. The absence of a standardized definition is indicative of the broad and evolving nature of these systems, which can vary widely in terms of functionality, design, and purpose. In general terms, a digital companion can be defined as a software-based entity that interacts with humans through digital platforms, offering personalized assistance, support, and companion characteristics. The most prominent work in this field is that of Wilks [Wil11], where the term "companion" refers to conversational software agents designed to accompany users over extended periods of time. *In this dissertation, we adhere to the explanation of a companion system as a technical system that exhibits the so-called companion characteristics, namely competence, adaptability, availability, cooperativeness, and trustworthiness [BW17].* These characteristics are implemented

---

through the interplay of cognitive processes based on perception, planning, reasoning, and interaction capabilities. The processes involve the perception and modeling of the user and the environment, the assessment of the overall situation, and the communication in open dialogues, exhibiting multi-modal behavior by selecting appropriate media, interaction, and dialogue strategies. For example, in the field of robot companions, Forlizzi et al. (2006) [FD06] and Beetz et al. (2008) [BSR<sup>+</sup>08] presented robots for household tasks like vacuum cleaning and assistive kitchens. Robots such as "Paro," a therapeutic seal for psychological therapy [WS07, WSMK08], and other robots [PMP<sup>+</sup>03] that provide guidance or reminders to elderly users. Particularly relevant in elderly care for emergency alerts and tailored assistance [ACC<sup>+</sup>13] and [GZ09], environments monitor residents, assist with daily tasks, and can adapt to multiple users' needs and contexts. Features such as adjusting seat positions or radio volume based on user preferences and emotional states in a car could extend to autonomous cars, adapting routes and driving behavior [WYH03]. Systems like Emergency Landing Planner (ELP) assist pilots in emergencies by factoring in variables such as weather conditions to make optimal decisions [MPSS09]. Not fully mediated by technology, people seek tools that empower them to make choices and tailor their experiences to fit their individual needs.

Companions like Alexa can be conceived of as a social interface that employs "human-like social cues and communication modalities" with the objective of facilitating interactions with individuals. Its operational model is that of a "shallow" social representation of an individual [Bre03]. In the context of developing conversational agents, Cassell et al. (2000) [CBC<sup>+</sup>00] identified several system requirements, including the ability to recognize verbal and non-verbal input, the ability to generate verbal and non-verbal output, and the capacity to support conversational norms (e.g., turn-taking, feedback). The conversational functions of Alexa are constrained and do not fully align with these requirements. Alexa currently lacks the capacity to learn and does not possess any intrinsic objectives beyond the task it is instructed to perform by its users. This reveals a gap in understanding how to design generalizable, psychologically attuned digital companions. In addition to one's personal life, for one's professional life, according to the Joint Research Centre report 2024, EU workers reported feeling under-skilled when using new technologies, a clear indicator that many tools are not designed with user competence in mind <sup>3</sup>. The design of companion technology must take into account not only the user experience but also the user's confidence in their ability to develop competence. Also, technologies that focus solely on task completion rather than enhancing interpersonal connections fail to meet users' need for relatedness. This prompts the formulation of our first research question - ***RQ1: how can digital companion systems be designed to empower users with control (autonomy), help them develop skills, and foster a sense of capability (competence) and connection (relatedness)?***

There are diverse one-off case studies that employ companion technologies for particular demographic groups, for specific use cases, for example, a smart conversational agent

---

<sup>3</sup>[https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/understanding-workers-participation-digital-skills-training-2024-03-21\\_en](https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/understanding-workers-participation-digital-skills-training-2024-03-21_en) –Accessed Dec 2024

to assist older adults in the reminiscence process [NCB18], a digital companion for air travelers [GDSM20], which uses semantic technologies and speech recognition to enhance their airport experience, or a digital agent that can support individuals experiencing stress-related exhaustion in managing their daily activities [JL19]. However, mainstream companion technologies like Siri and Alexa, designed for a broader audience, unfortunately, provide their functionality in a highly uniform manner, highlighting the gap between tailored, context-aware companions vs generalized smart assistants. The system does not differentiate between user types or individual users, regardless of their experience with the system or the specific function they require. The obstacles to comprehensive use of these innovative products and services also vary depending on the user, the situation, and the system in question. With many off-the-shelf virtual assistant devices, users are left with no alternative but to explore the system's functionalities independently. This can impede the user experience, cause frustration, and foster a bad attitude towards technology, which may ultimately result in a loss of interest in continuing to use the system or using it in a very limited capacity, and may also lead to the user not considering the system a companion. This leads us to our second research question - ***RQ2: what are the characteristics offered by the technology that is perceived as "companion" characteristics?*** It is an important aspect of designing systems that are partners with people, not just tools.

Design approaches in digital technology have shifted significantly over time. In the 1980s, the emphasis was on task efficiency, later expanding in the 1990s to include usability, guided by experimental methods focused on cognition and perception. In the 2000s, as technology became more wearable and embodied, designers began considering social and cultural contexts. The focus moved toward user experience (UX), centering the human rather than the machine, and highlighting emotion, enjoyment, and meaning-making [Has10, Nor14]. Researchers drew on ethnography [Suc87], phenomenology [Dou01], and emotion psychology [Pic00] to better understand these experiences. As technologies have become ubiquitous and increasingly automated, we are in the midst of an explosion of interest in the psychological impact of technology design. This pivot is going in two directions, with those interested in harnessing this impact (e.g., through motivational design and behavior change) and those affected by it (e.g., through manipulation, attention hijacking, etc.). Fueled by rapid advances in companion technology, there is now a growing recognition that people have a right to digital experiences that support, rather than hinder, their goals, values, and psychological needs. The evokes specific psychological responses and expectations among its users, particularly in the context of their social interactions [NST94]. Designers and developers of companion technologies need to ensure that they play the right roles and contribute to users' productivity and well-being. Therefore, we propose that a need fulfillment perspective can be an inspiring lens for companion design.

This dissertation is grounded in Self-Determination Theory (SDT) [DR08], which identifies autonomy, competence, and relatedness as key psychological needs for intrinsic motivation. The aim of this work is to design digital companion systems that support these needs.

Building on existing literature and empirical research, multiple case studies were conducted across different domains. These systems combine proactive and reactive features and employ various modalities (auditory, visual, haptic) to support meaningful human-machine collaboration. By exploring the user perspective, insights are gained on how companion technologies can be best designed. The data gathered is then synthesized and reflected upon, with implications, limitations, and suggestions. *For RQ3, we present design guidelines to support researchers and practitioners in creating technologies that meet users' psychological needs and are experienced as genuine companions.*

## 1.1 Research Questions

The preceding research questions are investigated in this dissertation (refer to Table 1.1). RQ1's aim is to provide a more nuanced comprehension of the design of companion systems, drawing upon existing theories pertaining to psychological needs and well-being, in combination with the design and testing of interaction techniques through a case study approach. This has enabled us to investigate the characteristics and parameters that facilitate the relationship between individuals and technology. In addressing RQ2, the objective is not merely to reflect on the feasibility of utilizing the technology and the modalities of interaction within a specific context. Rather, we seek to extend the understanding to provide insights into potential avenues for the design of future systems to better serve as a companion. Ultimately, for RQ3 the investigation informs the development of guidelines for the design and development of companion technologies, ensuring that the resulting solutions align with the psychological needs of users.

Table 1.1: Summeryzed Research Questions.

No.	Research Question
RQ1	How can digital companion systems be designed to enhance autonomy, competence, and relatedness in user interactions?
RQ2	What are the defining characteristics that enable individuals to perceive technology or artifacts as a "companion"?
RQ3	Which guidelines can be derived for the design and development of companion technologies to ensure alignment with user psychological needs?

## 1.2 Methodology

Our research is grounded in human-centered design and evaluation methodologies [LFH17, Fie02]. Throughout this work, we iteratively design the companion systems, tackling a specific application scenario, with the design process involving consideration of parameters related to autonomy, competence, and relatedness, comparison between feedback modalities, and assessment of user perception and performance through user studies. This approach enables the accumulation of knowledge and the derivation of

insights, which in turn informs the development of guidelines. Both subjective and objective data are collected and recorded. A mixed-method approach is employed [Lee19], combining both qualitative and quantitative research methods. The efficacy of this approach lies in its ability to provide a more comprehensive understanding of the research problem by capturing both the breadth of data through quantitative analysis and the depth of insights through qualitative exploration. By a combination of data from multiple sources, the mixed-method approach enhances the validity and robustness of our findings.

## MIXED METHOD RESEARCH APPROACH

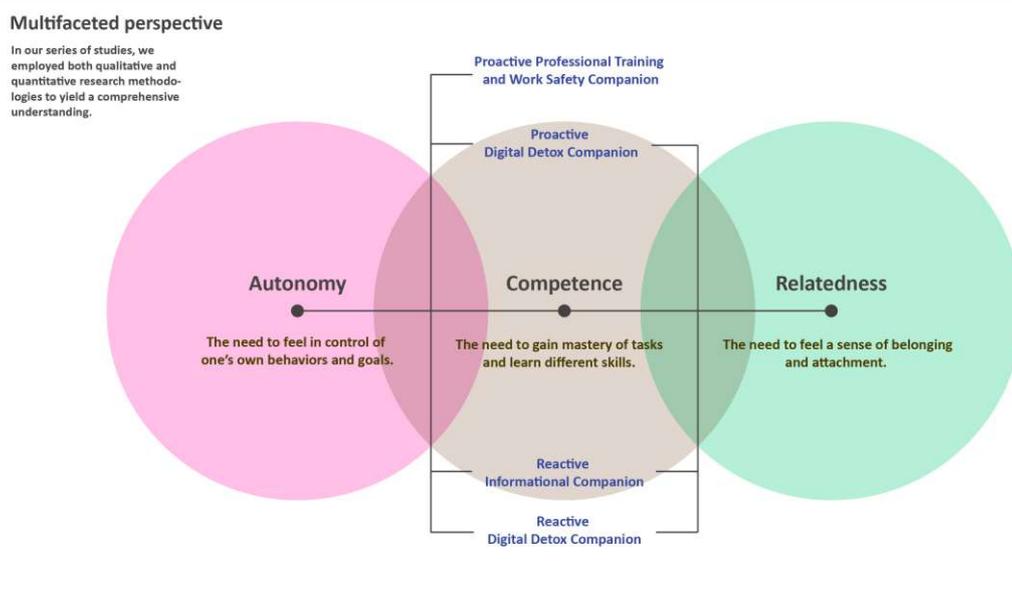


Figure 1.1: Case studies domains linked to the SDT aspects.

We developed and examined companion systems for applications such as professional training, information gathering, and digital detox, as illustrated in Figure 1.1. The design of companions incorporates both proactive and reactive features (detailed information on the definitions of these terms can be found in Section 2.1). In the realm of professional training and work safety, studies investigate the effectiveness of companion technologies with VR and AR, with a focus on enhancing user autonomy and competence. The digital detox category explores interventions ranging from digital nudges to smartwatches and tangible devices, all aimed at reducing digital addiction and fostering self-regulation. We designed informational companion systems that delve into interactive digital narratives with the objective of promoting a cause or raising awareness and encouraging action. These systems emphasize the concepts of autonomy, competence, and relatedness. Metrics such as task performance, engagement, and user perception were operationalized through a combination of survey instruments (e.g., Likert-scale responses), behavioral data (e.g.,

usage logs, interaction patterns), outcome-based measures (e.g., task accuracy or time on task), as well as qualitative methods such as interviews and diary studies to capture in-depth insights.

## 1.3 Research Contribution

In addressing the research questions posed, this dissertation makes contributions in two main established areas.

### 1.3.1 Theoretical Contribution

The traditional user experience frameworks often neglect the motivation and well-being aspects of companion interaction, focusing primarily on functionality. By applying SDT principles, this research aims to bridge this gap and create companion technologies that foster meaningful engagement. We examine the impact of SDT principles on user experiences across a range of companion technologies, both proactive and reactive. We explore how design features can enhance autonomy by providing users with control over their interactions, fostering competence through structured learning opportunities and feedback mechanisms, and promoting relatedness by incorporating novel interactions. This dissertation makes a novel theoretical contribution through its 12 design guidelines, derived from the empirical work. These guidelines are of substantial value to researchers, designers, behavioral psychologists, and developers in the creation of companion technologies that address user needs, enhance usability, and promote engagement across a range of applications.

### 1.3.2 Artifacts Contribution

Figure 1.2 presents all the prototypes created for this dissertation.

#### Professional Training and Work Safety Companion:

**VR Training Companion System:** This prototype was designed for knowledge transfer in electrical engineering and medical training. The companion system uses virtual reality (VR) to create immersive training environments. For the electrical engineering training, the VR environment simulates a flat where trainees perform tasks like checking the fuse box and using a voltage tester. In the medical training, participants practiced procedures like wound dressing and medicine administration using a VR companion.

**SkillLab AR-based Craft-work Learning Companion:** This prototype utilizes augmented reality (AR) and electrical muscle stimulation (EMS) to support learning craft-work skills, specifically floor lamination. Users wear Microsoft HoloLens, which provides AR guidance overlaid in the real world, while EMS provides haptic feedback

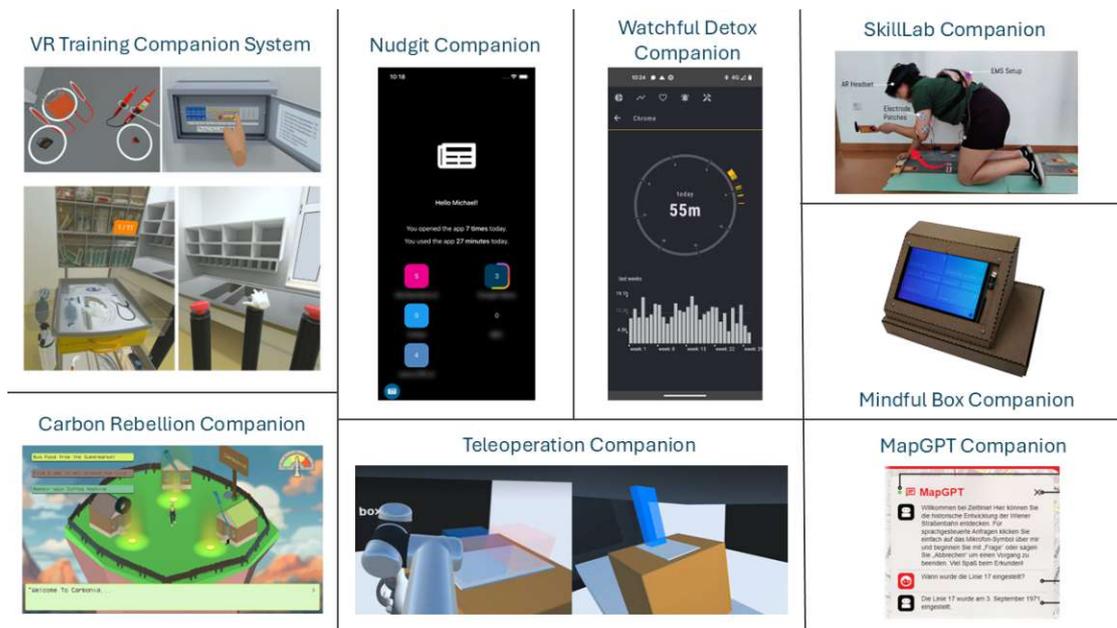


Figure 1.2: Overview of prototypes developed for this dissertation.

to guide their movements. The companion system uses a Structure-Behavior-Function framework to present information and offers scaffolding techniques to support learning.

**Teleoperation Companion:** This prototype explores the use of EMS to enhance the teleoperation of robots, particularly for obstacle avoidance. Users control a robot arm in VR while receiving haptic feedback through EMS when the robot is near an obstacle.

**Digital Detox Companion:**

**Nudgit Companion:** This prototype uses digital nudges to reduce online news consumption. It presents users with a limited feed of news articles selected based on their preferences. Additionally, the prototype incorporates three types of nudges: content filtering to hide negative news, contextual interruption to promote awareness of usage patterns, and social comparison to showcase peers’ behaviors.

**Watchful Detox Companion:** This prototype explores smartwatch-based interventions to promote digital well-being. The prototype leverages smartwatch functionalities such as heart rate monitoring and sleep tracking to provide users with insights into their smartphone usage patterns. It also provides features that centralize access to time and notifications on the smartwatch, reducing the need to interact directly with the smartphone.

**Mindful Box Companion:** This is a tangible prototype designed to encourage mindful smartphone usage and reduce screen time. The prototype consists of a physical chest that users can lock their smartphone or tablet in. The chest utilizes solenoid locks controlled by a microcontroller, and users can set time limits through an app interface on a tablet embedded within the chest. It incorporates additional features like gentle wake-up support and meditation assistance to promote a positive user experience.

#### **Informational Companion:**

**MapGPT Companion:** This prototype utilizes Large Language Models (LLMs) to facilitate natural language interactions with Geographic Information System (GIS) applications. Users can query the system using natural language instead of complex logical queries, making GIS applications more accessible to novice users. MapGPT incorporates domain knowledge from the GIS database and utilizes the OpenAI Assistants API to process user queries and generate responses.

**Carbon Rebellion Companion:** This prototype employs data-driven narratives to educate individuals about climate change and encourage climate action. The prototype features an interactive narrative where players make choices that impact a virtual CO<sub>2</sub> meter, representing Austria's carbon footprint. The narrative highlights the communal impact of individual choices and encourages players to reflect on their role in climate change mitigation.

### 1.3.3 Empirical Contributions

To illustrate the breadth of empirical work, this dissertation presents a series of case studies spanning domains such as professional training, digital well-being, and information access. A synopsis of the methodological approaches and SDT dimensions addressed across these studies is provided in Table 1.2.

## 1.4 Dissertation Outline

This dissertation is made up of eight chapters divided into four parts. Figure 1.3 depicts the interplay between the different parts:

### **Part I: Introduction and Background**

**Chapter 1 - Introduction:** The first chapter of this dissertation introduces and motivates the topic, accompanied by a description of the methodology employed. The contribution is also outlined and a brief overview of the structure of the dissertation is given.

**Chapter 2 - State of the Art:** This chapter presents an overview of the current landscape of companion technologies, defines the characteristics of proactive and reactive systems, examines their role in supporting users, and identifies the limitations of the current approaches. It presents a comprehensive examination of the influence of psychological principles on interface design and provides a brief overview of how the metrics and evaluation methods employed in prior research have been adapted or expanded upon in this dissertation to assess the impact of SDT principles in companion technology.

### Part II: Proactive Companions

**Chapter 3 - Professional Training and Work Safety Companion:** This chapter explores the application of companion technology in professional training and work safety. It presents three case studies: Professional VR training companion, SkillLab companion, and SkillLab companion.

**Chapter 4 - Digital Detox Companion:** This chapter focuses on the use of companion technology for digital detox and promoting well-being. It presents two companions: Nudgit Companion and Watchful Detox. These companions explore the use of digital nudges to reduce online news consumption and promote mindful smartphone usage.

### Part III: Reactive Companions

**Chapter 5 - Informational Companion:** This chapter examines the design and evaluation of informational companions. It presents two companions: MapGPT Companion and Carbon Rebellion Companion. MapGPT uses LLMs to facilitate natural language interactions with GIS, while Carbon Rebellion employs data-driven narratives to educate individuals about climate change.

**Chapter 6 - Digital Detox Companion:** This chapter introduces a tangible opt-out solution, the Mindful Box, designed to encourage mindful smartphone usage and reduce screen time. It discusses the chest's features, including locking mechanisms and additional functionalities like gentle wake-up support and meditation assistance.

### Part IV: Synthesis and Conclusion

**Chapter 7 - Synthesis and Reflection:** This chapter synthesizes the findings from the previous chapters, drawing connections between user experiences and the principles of SDT. It discusses the impact of companion technology on user autonomy, competence, and relatedness in both proactive and reactive systems. This chapter sets forth action-oriented guidelines.

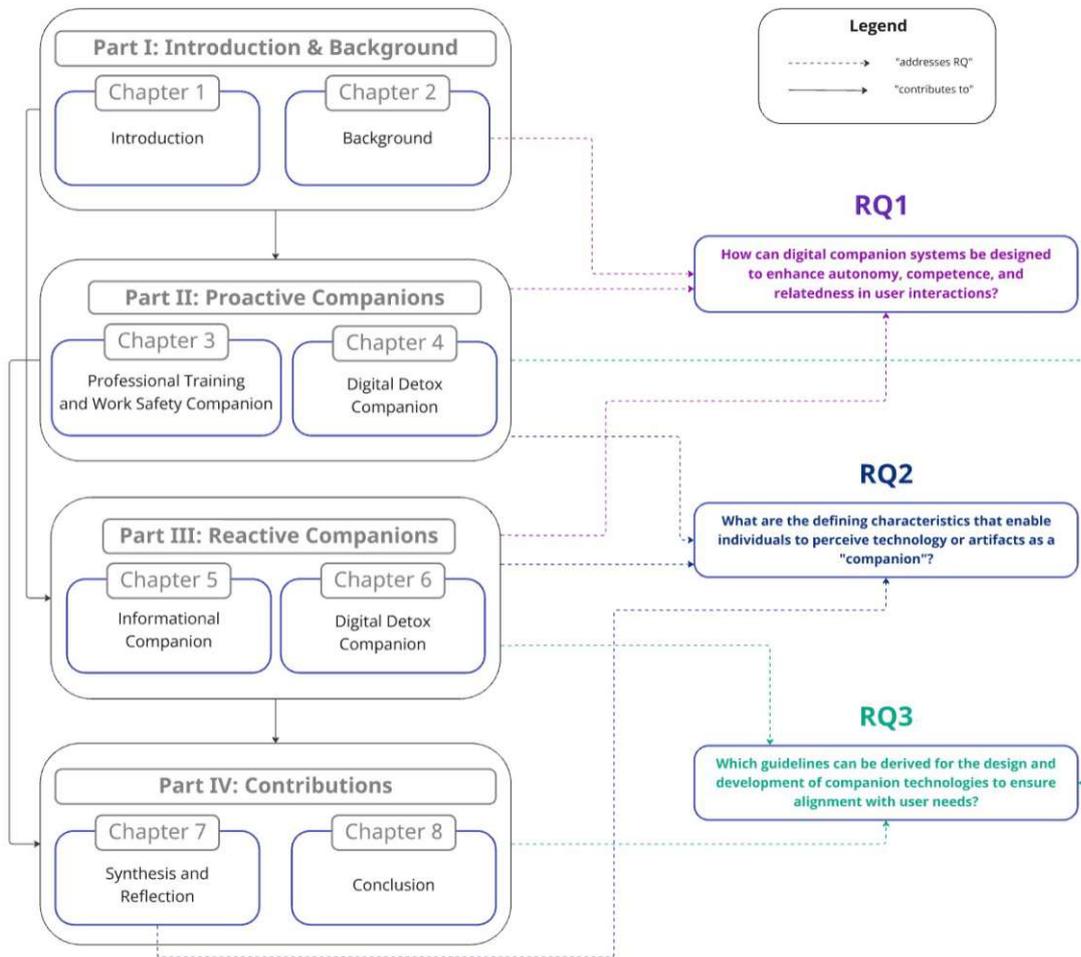


Figure 1.3: This chart illustrates the flow of chapters and their contributions to the research questions.

**Chapter 8 - Conclusion:** This chapter summarizes the key findings of the dissertation and restates its contributions to the field of companion technology design. It also outlines directions for future research, including exploring the evolution of user relationships with companion technologies, and expanding their application into new domains.

Table 1.2: Summary of Empirical Contributions

Case Study	Methods Used	SDT Dimensions	Key Insights
<b>Professional Training Companion</b>	Workshops, Observations, Semi-structured Interviews	Autonomy, Competence	Enabled self-directed exploration and practice, boosting motivation and skill confidence.
<b>SkillLab Companion</b>	Lab Study, Semi-structured interviews	Autonomy, Competence	Provided embodied, real-time feedback while preserving user agency, enhancing learning and confidence.
<b>Teleoperation Companion</b>	Lab Study, Survey	Autonomy, Competence	Supported shared control improving competence and collaboration between human and companion.
<b>Nudgit Companion</b>	Lab Study, Surveys	Autonomy, Competence, Relatedness	Enabled intentional digital media use through personalized nudges, supporting self-regulation.
<b>Watchful Detox Companion</b>	Field Study, Usage Tracking, Survey	Autonomy, Competence	Promoted awareness and control over digital habits, reinforcing self-efficacy and regulation.
<b>MapGPT Companion</b>	Lab Study, Surveys, Think-aloud	Competence, Autonomy	Lowered complexity of technical map-based systems, empowering users with confidence and independence.
<b>Carbon Rebellion Companion</b>	Lab Study, Interactive Narrative, Survey	Autonomy, Competence, Relatedness	Encouraged reflection and connection to collective causes through emotionally engaging narratives.
<b>Mindful Box Companion</b>	Field Study, Interviews, Usage Logs	Autonomy, Competence, Relatedness	Enabled goal setting and habit formation, supporting user control and capability development.

# Background

This chapter provides an overview of companion technologies, outlining the characteristics of proactive and reactive systems with examples from prior work, and the limitations of existing approaches. It explores the implications of psychological principles for interface design and briefly summarizes how this dissertation contributes to existing work by applying SDT principles to companion technology.

## 2.1 Proactive and Reactive Companion Technology

Companion technology is transitioning from basic human-computer interactions to human-companion relationships. The focus is now on designing technologies that go beyond efficiency and usability [ZvdHE16]. Instead of being seen as simple tools, these technologies are now seen as entities capable of social and emotional interaction [SGM21, NW20]. This shift has been made possible by advances in speech and language technologies, the semantic web, and systems that combine different modes of communication, leading to intelligent and personalized interfaces that turn interactions into relationships [BM10]. Research emphasizes the creation of "digital companions" that help users form personal connections and emotional bonds. A key challenge for designers is to move beyond a focus on efficiency to include features such as personalization, memory cues, and emotional connections [ZvdHE16]. Companion technology has been applied across a range of domains. The most prominent application area is robotics and within this domain, applications range from socially interactive systems such as bartender robots that use AI planning and multimodal input to manage customer interactions [PF13], to domestic service robots that assist users with daily tasks such as vacuuming [FD06], kitchen assistance [BSR<sup>+</sup>08], or more general household tasks. In healthcare and elder-care, companion technology includes both mobile robotic platforms and embedded smart devices [BHR<sup>+</sup>09]. Beyond robotic forms, non-anthropomorphic companion systems also assist people with cognitive impairments or disabilities, such as devices that assist people

with dementia with hand-washing routines [PHWH14] or intelligent tools that help blind users navigate their environment [DB09].

Intelligent environments and smart homes are another major application area. For example, smart homes for patients can monitor movement patterns, detect emergencies, and notify caregivers or emergency services when needed [RDN<sup>+</sup>02]. In the context of driver assistance, modern vehicles equipped with companion like features adapt to driver preferences, stress levels, and environmental conditions [WYH03]. For example, systems may adjust seat position or radio volume based on the user's profile, or provide emotional support by adjusting route choices based on the driver's stress indicators. Public service systems have also incorporated companion like functionality. One more example is an adaptive ticket vending machine that uses sensors to interpret user behavior, such as whether a person is distracted by a phone call or talking to another person [GHG<sup>+</sup>15]. In such cases, the system avoids misinterpreting unrelated gestures or spoken language as input. Personal digital companions and task planners are a growing area where systems that help users set up home entertainment devices or manage the functionality of smartphones are using AI planning and natural language generation to provide step-by-step guidance and personalized explanations [BBG<sup>+</sup>11, HSW12].

Companion systems can be broadly categorized based on interaction style. At one end of the spectrum are reactive companions, at the other, proactive. Proactive companions are digital systems that aim to predict what users need and act on it without being asked [GVM24]. They keep track of the user's context, surroundings, and past behavior to offer help or information at the right time [GMRC20]. For instance, a smart home system might adjust the temperature based on weather and user habits, a digital assistant could remind users about appointments by checking their calendar and travel plans, or a fitness tracker might suggest workouts based on activity levels and goals. Spirig et al. (2021) presented two expert digital companions for employees working in an office and a shopfloor environment [SGM21], which take advantage of the following: the decoupling that the W3C WoT Thing Description provides to interact with and control devices and other tools, a Knowledge Graph to provide richer descriptions of elements in the environment, computer vision to perceive the physical world and mixed reality as the medium to deliver assistance to workers. Digital companions can range from being fully reactive to highly proactive [ERM18]. Fully autonomous companions act on their own without user input, often found in gaming environments where they enhance the experience. Semi-autonomous companions strike a balance by letting users provide input or set preferences while still taking proactive steps. Factors like the companion's role, the setting it's used in, and user preferences help define the right balance between acting on its own and waiting for user commands. While these systems can be helpful, they also face challenges like predicting needs accurately, avoiding being intrusive, and ensuring privacy and control [YSSMM12]. Proactive systems, while promising enhanced assistance, raise concerns about user control. Users may feel uncomfortable with systems making decisions autonomously [GMRC20].

Reactive companions, on the other hand, only respond to specific requests or commands

from users [GVM24]. They wait for input, then act or provide information as needed. Examples include a digital assistant that plays music when asked, a search engine that finds information based on a query, or a navigation app that gives directions when a destination is entered, like Amazon Echo, which reactively performs tasks based on user voice commands. The main challenges for reactive companions include understanding user commands, giving accurate information, and handling unexpected inputs smoothly. Both reactive and proactive systems encounter difficulties in accurately and comprehensively understanding user needs and preferences. This limitation can be attributed to a scarcity of robust user modeling and the challenge of interpreting nuanced cues or implicit feedback. It is necessary to develop more sophisticated user models that incorporate psychological profiles, which extend beyond the scope of interaction history [NORV<sup>+</sup>]. In addition, enhancements to natural language processing and sentiment analysis capabilities would facilitate a more nuanced comprehension of user requests and feedback.

## 2.2 Psychological Needs in Companion Technology Design

HCI draws upon fields such as philosophy and psychology, sharing conceptual similarities with these disciplines but also exhibiting differences. Therefore, to examine companion technologies, we turn to the psychological needs literature. Psychological needs have previously been used as a means of explaining the user experience of interactive technologies [HDG10]. This categorization provides a framework for analyzing the diverse range of needs that companion technologies can address [PK12]. For instance, a companion robot could provide stimulation through novel interactions, foster identification by allowing users to personalize their appearance or behavior, and evoke personal memories through shared experiences. Specifically, Hassenzahl et al. (2010) highlighted the significance of psychological needs in the context of experience-oriented technology design [HDG10]. Sheldon et al. (2001) conducted three consecutive studies with the objective of exploring the importance of a variety of psychological needs [SEKK01]. From a variety of theories of psychological need fulfillment, they derived and explored ten psychological needs: self-esteem, autonomy, competence, relatedness, pleasure-stimulation, physical thriving, self-actualization-meaning, security, popularity-influence, and money luxury. The four most salient needs identified in the study were self-esteem, autonomy, competence, and relatedness. Self-esteem and security also emerged as significant contributors to satisfying user experiences [PK12]. Sheldon et al. (2001) conducted research that revealed the importance of specific needs for well-being [SEKK01]. For instance, Laschke et al. (2020) focused on designing medical technologies to support radiologists' well-being [LBNH20]. Two applications were developed: Accomplishment Library, allowing radiologists to store and share meaningful cases, addressing needs for competence, meaning, and relatedness, and Likelist, enabling feedback and communication between radiologists and referring physicians, addressing needs for competence, popularity, and collaboration. Both tools aimed to enhance professional satisfaction and teamwork. These findings align with and extend those of the Self-Determination Theory as proposed by Ryan and Deci [RD00].

SDT is one of the most widely studied and applied human motivation frameworks in

psychology [RDDD<sup>+</sup>22]. For more than four decades, many of its central principles have been repeatedly evaluated in meta-analyses, and it has been actively and increasingly studied [GRS<sup>+</sup>19, RDDD<sup>+</sup>22, NNP<sup>+</sup>21]. The strong interest in the theory stems partly from its relatively unique focus on the importance of human autonomy and volition: how environmental factors either support or inhibit the ability of humans to behave willingly, proactively, and in a sustained manner [RDDD<sup>+</sup>22]. SDT proposes that there are specific factors that influence people’s ability to develop and maintain motivation to engage in certain behaviors, thereby reducing their dependence on support from external sources. Basically, sources of motivation may be more or less internal (based on an inherent desire to perform) or external (based on external factors like fear, reward, or duty). According to SDT, while interventions that rely on extrinsic forms of motivation may work in the short term, they typically fail to sustain motivation in the long term, or after the intervention has ended [DR13]. Conversely, if the motivation is internalized, the behavior can become self-determined, at which point the intervention may no longer be necessary, and the change in behavior tends to be persistent [RD17].

An important opportunity for companion systems, therefore, is to use SDT to change the nature of the scaffolding mechanisms in the direction of a more internal regulation of motivation. In other words, to help people internalize the values and goals of the companion intervention so that it feels less like something they have to do and more like something they do voluntarily because they find it intrinsically pleasurable and/or personally meaningful. This change is facilitated by the relevant satisfaction of three basic psychological needs that all people seem to have: needs for a sense of autonomy, competence, and relatedness. SDT provides a framework for developing behavioral interventions and suggests techniques for influencing their constructs [FDGT12, GRS<sup>+</sup>19, RDDD<sup>+</sup>22, NNP<sup>+</sup>21]. There is strong evidence for the effectiveness of SDT-based interventions in multiple domains, including physical activity [END08, WGS<sup>+</sup>06], environmental behaviors [PS08], tobacco use [WNP<sup>+</sup>09], and adherence to medical treatment [WMZ<sup>+</sup>04], as demonstrated in several intervention studies and meta-analyses. Consequently, HCI researchers are beginning to highlight the benefits of integrating SDT constructs into interface design and the importance of addressing these basic needs at different stages of technology adoption [BDT<sup>+</sup>22, PCR18]. A handful of HCI papers have begun to consider how to support these needs through design features, particularly for companion technology.

The design of companion technologies must consider the dynamic and contextual requirements of users, emphasizing the need for diverse companion roles and interaction styles depending on the context of use. For example, a study focusing on software architects found that they preferred active companions in work settings, whereas they favored passive companions in leisure contexts [NDP18]. This suggests that companion technologies designed for work should prioritize needs related to competence, efficiency, and productivity, while those designed for leisure might focus on stimulation, pleasure, and relaxation. Also, the emphasis should be on designing companion technologies that prioritize delivering positive experiences [BZSP19]. Burmester et al. (2019) designed two digital companion prototypes for workshop planning, with Hugo focusing on fostering

positive user experiences by addressing needs like feedback, security, and collaboration [BZSP19]. Results showed Hugo elicited more natural interactions and positive perceptions compared to the neutral companion, despite similar functionalities. While research has highlighted the importance of fulfilling psychological needs for positive user experiences, understanding the specific needs tied to different interaction contexts remains a challenge [NDP18]. Researchers have explored the development of digital companions for work contexts with a focus on fostering positive experiences, however, several challenges remain to be addressed [KHY<sup>+</sup>19]. These include identifying appropriate data sources and knowledge bases to support the functionality of digital companions, enabling them to understand and adapt to contextual information effectively, and striking a balance between being useful and avoiding overwhelming users. Further research is needed to fully explore the potential of companion technologies in enhancing well-being and to develop comprehensive design guidelines [LBNH20]. This includes a deeper understanding of the intricate interplay between technology, psychological needs, and context.

## 2.3 Interaction Modalities in Companion Systems

Two closely related but conceptually distinct dimensions to distinguish are: user interaction input and system behavior output. The first dimension as discussed in Section 2.1, reactive versus proactive system behavior, describes how the system reacts to or predicts what the user needs. The second dimension, explicit versus implicit interaction, describes how users interact with the system. Explicit interactions are deliberate and conscious actions, such as issuing voice commands, clicking buttons, or making gestures. On the other hand, implicit interactions are non-conscious and involuntary signals that the system detects and interprets. These signals can include things like where someone is looking, their posture, facial expressions, or physical reactions. These two dimensions often intersect: explicit versus implicit and reactive versus proactive. For example, a system might suggest a break on its own because it detects signs of fatigue, like facial tension. It might also respond to a direct request for directions, such as when a user says, “*Take me to the nearest pharmacy.*” In companion systems, these two dimensions often intersect and inform one another, shaping the nature of the interaction.

The companion system processes user input, including speech, gestures, and emotional cues, together with environmental data to create a combined representation of the user’s state and context. This representation is used to generate plans, recommend actions, and adapt system responses. The interaction modalities of companion systems involve the integration of multi-modal user inputs, such as speech, gestures, and emotional cues, which the system uses to adapt its responses and provide personalized assistance through different output channels, such as visual, auditory, or tactile feedback [EEV<sup>+</sup>12]. A driver assistance system records spoken commands gestures such as pointing, and facial expressions of stress [GLSG09]. For example, if the driver looks anxious, the system can recommend calming routes or adjust driving preferences accordingly. For another scenario where a dyslexic child learns with a caregiver, cameras capture facial expressions and body movements, while wearable sensors measure physiological data like heart rate and

skin conductance [BCDM<sup>+</sup>12]. This enables real-time adjustments in teaching methods. Data collected from the child's environment, including video, audio, and physiological signals, is analyzed to provide suggestions or alarms to caregivers, such as recommending new activities when the child's engagement drops. The system integrates multi-sensory teaching strategies by leveraging the strengths of dyslexic children, such as heightened sensory receptivity.

Kapoor et al. (2007), for example, an automated method for predicting frustration was presented, utilizing multi-modal non-verbal cues, including facial expressions, head movement, posture, skin conductance, and mouse pressure data [KBP07]. Peters et al. (2008) modeled the user level of interest and engagement using eye gaze and head direction information during an interaction with a virtual agent displaying shared attention behavior [PAKdS08]. One of the most significant challenges in multi-modal affect recognition is the fusion of different modalities. The fusion of features from different modalities of expression can occur at varying levels, including the feature level and the decision level. Results from studies in psychology and neurology indicate that the integration of disparate perceptual signals occurs at an early stage of human stimulus processing [Ste93]. This indicates that the processing of different modalities of expression should occur within a joint feature space, rather than through a late fusion. The relationship between features derived from different modalities is currently unclear, as they often exhibit complementary and redundant characteristics. It is, therefore, essential to emphasize that alternative combination strategies beyond the direct fusion of features must be subjected to further investigation. The development of innovative techniques for multi-modal fusion must consider the intrinsic relationships and correlations between the feature sets present in the different modalities [SGM07, ZHL<sup>+</sup>06]. The design of companion technologies should integrate insights from prior work on multi-model systems to create systems capable of dynamically adapting to complexity to provide more accurate, context-sensitive responses, thereby improving user experience. Empirically testing the companion's interaction modalities is crucial to identifying and addressing potential ambiguities and errors in real-world scenarios. Choosing the wrong interaction modalities can significantly complicate the interaction between users and digital companions, leading to inefficiencies. For instance, if a digital assistant misinterprets voice commands in a noisy environment due to inadequate contextual awareness, the user may have to repeat or clarify requests multiple times, creating frustration and delays. Similarly, in smart home systems, if a gesture-based control misinterprets or fails to recognize intended actions due to poor calibration or conflicting inputs, the user may experience errors in executing tasks.

Electrical muscle stimulation (EMS) systems in HCI present an innovative interaction modality that directly interfaces with the user's body by stimulating specific muscles to elicit controlled movements [FKS22]. EMS systems bypass conventional input and output mechanisms, instead using electrical impulses to create physical responses, making them particularly suited for scenarios where tactile feedback or physical guidance is needed [KAH18]. By integrating precise muscle control, EMS expands the scope of multi-modal

interaction, bridging physical actions with digital responses to create highly adaptive and responsive interfaces in HCI. Despite its potential, EMS has not been extensively explored as an interaction modality for companion technology, partly because it compromises user autonomy and remains unfamiliar in everyday use. Integrating EMS into companion systems could, however, offer opportunities for more immersive and physical interactions. This thesis proposes investigating EMS as a novel modality to enhance user experience and functionality, balancing its benefits with considerations for autonomy and usability.



# Part II

## Proactive Companions



# Professional Training and Work Safety Companion

The selection of case studies in this chapter was guided by the need to explore real-world, high-stakes, or competency-based environments contexts where effective knowledge transfer, guided training, or cooperative task performance is essential, and where proactive companion technologies have the potential to meaningfully improve user outcomes. We explored diverse domains rather than limiting the investigation to a single application domain, to understand how assistive technologies work in different real-world contexts.

## 3.1 Professional Training with Single-User VR Companion

This chapter is based on our following publication:

### Publication

Shahu, A., Kinzer, K., & Michahelles, F. (2023, December). Enhancing Professional Training with Single-User Virtual Reality: Unveiling Challenges, Opportunities, and Design Guidelines. In Proceedings of the 22nd International Conference on Mobile and Ubiquitous Multimedia (pp. 244-256).

Virtual reality (VR) technology is increasingly finding its place in education and professional training due to a host of advantages it offers. These include the flexibility of learning from anywhere, the ability to practice hazardous tasks safely, and the allowance of errors [RMN21, GGBZ21]. VR enables the visualization of three-dimensional (3D) information and creates interactive settings that enhance the feeling of being immersed. This technology promotes learning by involving learners in interactive activities and dynamic interactions, enabling them to delve into and explore various objects and phenomena within the learning environment. This is particularly advantageous in fields

where authentic learning settings are impractical within a conventional classroom setup such as healthcare, aviation, and emergency response. By integrating 3D objects that replicate real-world items, and subsequently incorporating them into real-time virtual simulations [BC94], learners gain the opportunity to immerse themselves in a simulated reality [MN99]. Apprentices and trainees currently have limited opportunities to practice the tasks, making VR training a promising solution as it provides a safe environment for making mistakes and repeating efforts, which is crucial for skill acquisition [RMN21, SFLRS18].

Research has indicated that utilizing VR for learning can amplify motivation and interest, ultimately resulting in more effective learning outcomes and heightened self-confidence [HST19, MS11b, RMN21]. Moreover, virtual learning environments offer the advantages of affordability, safety, and increased flexibility. Numerous educational systems have effectively established impactful virtual learning environments [CR07, PCY<sup>+</sup>06]. The success of immersing individuals in a VR environment hinges on the extent of their engagement [SC03]. Educators are actively exploring ways to leverage this immersive quality of VR to enhance learners' willingness to participate in educational activities [HS08]. Despite the observed positive impacts of VR, particularly with head-mounted displays (HMDs), there remains a paucity of evidence on the optimal utilization of this technology for training, particularly in real-world scenarios [MPS<sup>+</sup>20, MBGM19, FGA<sup>+</sup>18].

Thoroughly assessing learning objectives, activities, evaluations, and seamless curricular integration is indispensable before embracing VR training, recognizing that it cannot wholly replace hands-on experience [JK18]. Nevertheless, as a supplementary learning tool, it holds the potential to enhance existing instructional techniques, thereby meriting serious consideration for effective and efficient training paradigms. Exploring the full scope of VR training's limitations and its accessibility across diverse demographics is of paramount importance [GGBZ21]. Furthermore, we must actively recognize and remove any barriers that might impede the adoption of VR training, while also shaping design and usage guidelines based on real-world VR training contexts.

Our research encompasses the development and assessment of functional prototypes for single-user VR companion applications using HMDs. The primary objective of this study is to contrast the learning outcomes of two cohorts: one utilizing VR training companions, and the other relying on printed materials. These learning exercises pertain to tasks that involve spatial orientation and procedural competencies. In addition, the study aims to identify suitable teaching and learning paradigms for VR training that consider the real-world context. The study also evaluates the acceptance of VR training companions, identifies potential barriers and obstacles, and delves into associated challenges. Through comprehensive exploration and comparison, this research investigates the deployment of VR training companions in various domains. Guided by the findings, the study furnishes recommendations for the future evolution of VR training that caters to a diverse array of users, including both learners and instructors. The objective is to harness the potential of this technology for long-term integration into professional training. By comprehending

the impact of VR training on learning outcomes, identifying best practices for design and use, and addressing potential challenges, the study endeavors to contribute to the formulation of efficient VR training curricula. These curricula have the potential to elevate safety and enhance skill acquisition within vocational education using a companion. A substantial component of our investigation is of an exploratory nature. Consequently, we have formulated the following research questions:

- **Research Question 1 (RQ1):** What are the opportunities and challenges of employing single-user VR companions in modern professional training in terms of accessibility, learning outcomes, acceptability, and technology motivation?
- **Research Question 2 (RQ2):** What are the best practices and recommendations for designing and implementing single-user VR companion training in a real-world context?

#### 3.1.1 Related Work

The existing literature highlights the multifaceted advantages of immersive VR training, encompassing heightened emotional engagement, enhanced learning processes, elevated motivation, and enjoyment [GGBZ21]. It has exhibited superior efficacy compared to video training or desktop VR, particularly in the context of procedural skills and the exploration of hazardous scenarios [RMN21]. Nonetheless, the effectiveness of immersive VR training hinges on trainer guidance and supervision, while also presenting limitations in terms of haptic feedback [MBGM19, TPG<sup>+</sup>21]. While it facilitates repetitive training without necessitating additional equipment and can truncate training time, its integration requires judicious consideration to maximize learning outcomes [MPGK15, BMA<sup>+</sup>19].

#### Virtual Reality in Professional Training

Initially utilized predominantly in military training, the broader adoption of VR across different domains remained constrained due to the prohibitive expenses associated with the required equipment [Car17]. However, with advancements in hardware and the gradual reduction in the cost of VR devices, the horizons of potential applications have expanded. VR has the capacity to replicate both real-world and imaginative scenarios, offering a secure avenue for immersive hands-on training. This evolution renders VR increasingly indispensable for educational and training contexts [GGBZ21, S<sup>+</sup>65]. Despite this, the integration of VR into mainstream education remains largely experimental, and its inclusion in standard curricula has yet to materialize [RMFW20].

VR training proves particularly invaluable in contexts where errors could result in personal or collective harm, or where real-world training is unfeasible, such as emergency preparedness or scenarios with products that do not yet exist [SRKS20]. The growing interest in VR simulations for vocational and safety training stems from their capability to facilitate the practice of critical and hazardous tasks within a safe and realistic environment [GGBZ21]. These simulations offer a diverse array of scenarios, featuring

personalized content, feedback, and varying levels of complexity [MBGM19, TPG<sup>+</sup>21]. The benefits of VR training encompass decreased fabrication time, cost-efficiency vis-à-vis traditional training, and the flexibility to repeat training sessions as necessary [TPB<sup>+</sup>17, SFLRS18, PLS<sup>+</sup>21]. Highly motivating and engaging for users, VR training fosters heightened learning efficiency, higher confidence, and easier recovery from errors than in real-world environments [MBGM19]. The interactive and immersive nature of the environment encourages experiential learning through real-time experimentation and exploration [PM08]. Studies have found that VR training is effective for training memory, procedural skills, spatial tasks, and orientational skills, primarily focusing on procedural skills for assembly and maintenance [RMN21, GGBZ21]. Evidence suggests a correlation between high immersion levels in VR applications and spatial memory capabilities [RMN21]. However, a crucial differentiation needs to be drawn between VR applications in educational settings and those geared towards occupation-centric professional training, as the latter is inherently more intricate and challenging to evaluate [RMN21]. Plotzky et al. (2021) found that although VR training theoretically enables self-directed learning without direct supervision, its effectiveness is notably enhanced when complemented by guidance and support from trainers [PLS<sup>+</sup>21]. Integrating VR technology into the curriculum is imperative, and it should be regarded as a complementary tool rather than a substitute for conventional learning methods, highlighted by the necessity of proper instructional guidance [MPGK15, BMA<sup>+</sup>19].

#### **Orientalional Skills in VR**

A study by Krokos et al. (2019) examined how spatial information representation impacts memorability and recall [KPV19]. They used a 3D virtual castle with designated information, similar to memory places. Participants were split into three groups: VR with HMDs, desktop 3D model, and a list of items. The VR group had better recall, focus, and presence. Even those new to HMDs outperformed desktop users in VR. However, König et al. (2020) had a different perspective, exploring the effects of VR and non-VR media on spatial learning [KKC<sup>+</sup>20]. Despite similar knowledge acquisition between the learning methods, the VR cohort displayed enhanced proficiency in judging straight directions between landmarks, while the non-VR group excelled in estimating cardinal directions. Schrom-Feiertag et al. (2017) orchestrated an experiment within a CAVE virtual environment to evaluate an indoor guidance system. Participants navigated through way-finding tasks, leveraging the inherent ease of movement within the CAVE setup [SFSS17]. Quantifiable metrics such as completion times, traveled distance, walking speed, and visual exploration were measured. The assessment extended to gauging participants' perception of presence in the virtual milieu. The results notably highlighted the effectiveness of virtual environments in scrutinizing human navigation behaviors and spatial orientation. These findings suggest that harnessing VR technology can yield substantial benefits in enhancing cognitive processes such as memorability, spatial orientation, and navigation.

## Presence and Immersion

The terms "presence" and "immersion" are often used to describe the VR experience, but their distinctions are not always clear, sometimes leading to confusion or conflicting definitions [Cal14]. Presence is the sensation of being in the virtual environment [LBR<sup>+</sup>15], while immersion relates to the technology that creates this sensation [BMA<sup>+</sup>19]. How immersive the technology is and how users navigate within it can affect presence, which then influences user acceptance and perceived utility [BLT<sup>+</sup>14, SLEL<sup>+</sup>20, WWW<sup>+</sup>18]. Immersive VR uses headsets and CAVEs. Questionnaires are often used to measure presence after a VR experience [SKHH19]. Understanding presence is important for creating new technologies and training scenarios.

## Fidelity

Fidelity is a key aspect in VR applications, commonly categorized into three types: display fidelity, interaction fidelity, and scenario fidelity (related to storytelling) [BC17]. Display fidelity pertains to the level of detail and realism in the visual elements, which can improve users' attention but does not necessarily increase their sense of presence in VR [Cal14]. Research by Buttussi and Chittaro (2017) explored different display fidelity levels in safety training, revealing that higher fidelity increased presence and engagement but didn't significantly improve learning outcomes [BC17]. Uncertainty remains regarding the impact of higher interaction fidelity on learning outcomes, especially in tasks involving physical actions. Further investigation is required to comprehend the role of scenario fidelity. Remarkably, Feng et al. (2018) noted that heightened fidelity and realism elevate engagement with the subject being taught [FGA<sup>+</sup>18].

## Procedural Skills

**Electricians:** In a study by Górski et al. (2021), an experiment centered around a VR training system for electricians was conducted [GGBZ21], exploring three distinct navigation and interaction methods. The objective was to identify the optimal fusion of interaction techniques and evaluate the viability of VR simulation for future electrician training within a facility context. Participants engaged in standardized scenarios, involving switching operations and simulated cable placement, with an assisting avatar offering brief tips. A pre-and post-questionnaire captured insights, and implementation times and hint usage were compared across different setups. Overall, 90% of participants found the technology useful, with 54.5% considering it a potential replacement for traditional training. In another study by Tanaka et al. (2017), a VR training system tailored for electricians stationed at substations was conceived and investigated as a supplementary training tool [TPB<sup>+</sup>17]. Users explored the facility and inspected equipment for errors. The study concluded that VR training effectively complements traditional training. A subsequent investigation delved into various movement methods and the broad applicability of such training, ultimately proposing teleportation as the default choice. As current training for electricians and network operators tends to focus on theoretical knowledge,

lacking practical experience, VR training fills a vital void in cultivating best practices [TPB<sup>+</sup>17].

**Healthcare:** As per Renganayagalu et al. (2021), VR training is widely embraced within the medical realm, with medical training-oriented VR systems exhibiting greater specialization and sophistication than those used in other sectors [RMN21]. While VR training in nursing education is relatively nascent and warrants further exploration, research such as the study conducted by Bracq et al. (2019) highlights VR's suitability for procedural training in nursing [BMA<sup>+</sup>19]. This is particularly evident for tasks requiring repetitive practice devoid of equipment or patient involvement. The study revealed increased interest in VR post-training, with age, gender, and gaming or VR familiarity exerting minimal influence on user acceptability. However, the study acknowledged the necessity for additional research to assess the real-world impact of VR training on procedural skills. In a comprehensive assessment, Plotzky et al. (2021) performed a systematic review of VR usage in nurse education, revealing systematic procedure training, emergency response training, soft skills training, and psychomotor skills training as the most common areas of focus [PLS<sup>+</sup>21]. Furthermore, Butt et al. (2018) delved into the effectiveness and user experience of a game-based VR simulation for urinary catheterization training, a procedure with limited opportunities for practice before patient interactions [BKEE18]. The VR simulation allowed hands-on interaction via interactive gloves, with both groups receiving expert feedback during their one-hour practice. Outcomes indicated a strong inclination toward repeated practice, and a retention test conducted two weeks later demonstrated comparable performance between groups. Intensive care nurses frequently grapple with chronic stress due to the persistent stressors of interruptions and time pressure. A study conducted by Weiß and Heuten (2023) within a virtual environment corroborates that both subjective and objective stress levels increase under these circumstances [WH23]. This finding highlights the feasibility of integrating stress inoculation training into nursing education curricula, particularly in scenarios that emulate safety-critical situations during early professional training. Overall, the VR simulation was well-received, with participants expressing a willingness to incorporate it into their practice.

**Safety Training:** Realistically simulating emergency training is a notable challenge that VR effectively addresses [SRKS20]. VR provides hands-on training, allowing trainees to engage in diverse scenarios and actively partake in various situations without actual risk. However, high-fidelity systems remain cost-intensive and primarily find use within the military domain [MPGK15]. Feng et al. (2018) explored the use of VR in serious games and evacuation training, finding that traditional training methods lack emotional engagement and feedback [FGA<sup>+</sup>18]. VR-based training yields several advantages, encompassing enhanced recall, immediate feedback, and the ability to study behavioral patterns [FGA<sup>+</sup>18]. Fire safety, in particular, stands as a significant application area, leveraging VR to replicate lifelike scenarios, amplify engagement, and evoke emotional responses. Lovreglio et al. (2021) conducted a comparative study between VR and

traditional video training for fire extinguisher usage [LDR<sup>+</sup>21]. The findings indicated that the VR group exhibited noteworthy knowledge gain and improved retention compared to the video group. Most participants favored VR training over video training, however, the study didn't directly compare their performance in real tasks. In a separate study by Makransky et al. (2019), immersive VR, desktop VR, and printed manuals were pitted against each other to teach laboratory safety to undergraduate students [MBGM19]. The immersive VR and desktop VR groups displayed significantly higher enjoyment and intrinsic motivation than the printed media group. The study highlights VR's potential to enhance enjoyment and motivation in learning, subsequently bolstering the effort put into learning. Furthermore, VR training's value extends beyond academic settings into real-world performance improvement.

#### 3.1.2 Approach

To formulate recommendations and guidelines for the utilization of single-user VR HMDs in professional training, our stance favors the adoption of a case study methodology. The case study approach stands as an optimal choice for delving into the connections between contextual conditions, phenomena, and underlying reasons. Additionally, employing a multi-case study approach proves valuable in dissecting differences and commonalities across diverse cases [BJ<sup>+</sup>08]. This methodology allows for a holistic comprehension of the subject matter by amalgamating both qualitative and quantitative data [AJL22]. The primary objective of this study is to introduce VR technology into professional training programs aimed at diverse target groups. We seek to enrich the conventional learning approach reliant on printed materials, images, and videos, by providing a more immersive and interactive learning experience. Our experimental framework was meticulously designed to leverage potential synergies, and these experiments were conducted within settings that closely resembled their real-world applications. These settings encompassed vocational schools, training facilities, and a simulated hospital environment. An iterative development approach was adopted, involving workshops with experts, mixed methods in experiments and field studies, and qualitative interviews focused on task-related measures to analyze the behavioral patterns of different groups and identify the underlying challenges for the effective use of single-user VR training. The interview aimed to assess participants' perceptions of VR training by inquiring about its strengths, weaknesses, satisfaction, improvement suggestions, the advantages of VR over conventional methods, and the potential integration of VR into education and training. Importantly, the same hardware devices, specifically the Oculus Quest 2, were used in all the case studies. The collected data not only shed light on potential opportunities and roadblocks within single-user VR HMD training but also contributed to the formulation of design guidelines.

#### Case Study 1 - Knowledge Transfer in Electrical Engineering

The research commenced by gathering requirements through a comprehensive analysis of similar projects in the literature. We used an iterative approach to develop a functional

prototype in collaboration with Mindconsole<sup>1</sup>. We held two workshops with experts and potential users to determine the content for the VR training scenario. In the first workshop, 8 trainers and experts from partners like AVL List GmbH<sup>2</sup> and WIFI Steiermark<sup>3</sup> participated. The second workshop involved 9 apprentices from AVL Training Center for Apprentices. The workshops aimed to pinpoint training scenarios that would be pertinent to both trainers and students. To uncover potential scenarios and learning material for the VR training, we delved into work accident statistics<sup>4</sup> and organized design-fiction workshops. This approach was undertaken with the objective of proactively identifying and mitigating potential forthcoming challenges within the training system and evaluating its advantages and disadvantages.

**Initial Findings:** In both workshops, participants focused on improving electrical engineering safety education, discussing VR scenarios for complex situations and the need for more hands-on learning. They noted that apprentices seek greater tactile experiences and often rely on self-guided online learning. The main challenge discussed was teaching the "Five Safety Rules" due to limited hands-on training opportunities, which can be addressed via the use of the VR companion. To address this, they proposed integrating VR scenarios for tasks like cable laying and power line work, although precision tasks may be challenging in VR due to restricted feedback. VR was considered beneficial for its safer and more realistic learning environment, along with the advantage of training at different locations.

**Study Design and Task:** Case study 1 was designed to simulate a flat with potentially damaged electric installations as shown in Figure 3.1. The objective was to follow a protocol and ensure that the basic protection according to DIN VDE 0100 is met [KS84]. The scenario encompassed 15 distinct variables, each representing a facet of electrical installations, as depicted in Figure 3.2. This includes elements such as impaired sockets and malfunctioning appliances. Ten electrical sockets at four distinct locations, or the fuse box itself, had the potential to have been damaged or incorrectly installed in the past. Manifestations of these issues included non-functioning sockets, visible burn marks, or improper installation. Furthermore, the following electrical devices may have incurred damage: a standing lamp, a table lamp, a television, and a toaster. Each time a scenario was initiated, these variables were randomly generated. The simulated apartment comprised three rooms, granting users the freedom to traverse and interact with diverse measuring devices. Within the proximity of the user's access, an imaginary conveyor belt housed various measurement instruments, including a voltage tester, a test lamp, and two locks designed for securing fuses and the fuse box. The user had the discretion to choose the methods and order for examining the essential electrical

---

<sup>1</sup><https://mindconsole.net/> – Accessed July 2022

<sup>2</sup><https://www.avl.com/de> – Accessed July 2022

<sup>3</sup><https://www.stmk.wifi.at/> – Accessed July 2022

<sup>4</sup><https://www.statistik.at/en/statistics/labour-market/labour-and-health/accidents-at-work-work-related-health-problems> – Accessed July 2022

safety measures in the residence. The study was conducted in two distinct phases. The first phase commenced with a kickoff workshop, wherein the project was introduced, and participants were given an ID and tutorial on how to use the VR headset and interact with the scenario. Participants were granted access to the VR headset for a duration spanning two to three weeks. At the training facility of AVL List GmbH, VR training took place voluntarily during breaks. Conversely, Landesberufsschule Voitsberg<sup>5</sup> and Energie Steiermark AG<sup>6</sup> seamlessly integrate VR training into their standard curriculum. Culminating this phase, a qualitative semi-structured interview was conducted to gather insights. The objective of these interviews was to accumulate insights concerning the acceptance and viability of VR training. Carried out via telephone, each interview spanned approximately 20 minutes. Participants were extended invitations during the inaugural kick-off workshop, resulting in a total of 30 participants being interviewed. The data collected from these interviews was analyzed employing thematic analysis by three researchers. The analysis of interview data in this study followed a structured process of transcription, coding, category creation, and theme development. Each interview's data categorization underwent a second review by at least one researcher to determine the final categorization.



Figure 3.1: Hallway, the starting point of the scenario (left), and the living room of the virtual flat (right).

**Participants:** The study involved 30 apprentices drawn from diverse project partners, including entities such as AVL List GmbH, Landesberufsschule Voitsberg, and Energie Steiermark AG. These collaborators expressed future interest in incorporating VR training systems and requested their respective apprentices to participate in the study. Prior to involvement, all participants, as well as their legal guardians in the case of minors, were comprehensively briefed about the study's nature and objectives, ultimately granting their explicit consent to partake. The majority of study participants were male, while the number of female apprentices partaking was limited to 5. Merely 10 individuals

<sup>5</sup><https://www.lbs-voitsberg.ac.at/> – Accessed July 2022

<sup>6</sup><https://www.e-steiermark.com/ueber-uns/unternehmen/management> – Accessed July 2022



Figure 3.2: Voltage tester, test lamp and two locks (left), and the fuse box in the hallway (right).

surpassed the age of 20. The mean age of participants was calculated at 18.2 years, with the youngest participant aged 16 and the eldest aged 27.

**Results:** Individuals involved in the field study exhibited a moderate to strong inclination towards technology, as indicated by the ATI-S scale [FAW19]. The average score on this scale, which ranges from 1 to 6, was 4.25 (SD = 0.84). The overall training approach garnered positive feedback, particularly for its alignment with contemporary learning preferences. A participant reported *"You can learn better that way, today's youth can deal better with such a system and the Internet than with lots of slips of paper, we are more used to that. That something like this is developed at all is great!"* (p. 10). Participants noted that young learners are better equipped to engage with digital systems like VR companions compared to traditional methods [This finding contributes to Chapter 7, subsection 7.3: User Autonomy and Control.] The innovative nature of VR-based training was well-received. Students who pursued electrician apprenticeships found value in hands-on experience for tasks that were previously only taught theoretically. Conversely, participants in other apprenticeships highlighted unfamiliar and complex content but appreciated the exposure to different specializations and scenarios. *The need for varied levels of difficulty was acknowledged [This finding contributes to Chapter 7, subsection 7.3: Personalization and Adaptability.]* A small portion of the participants encountered initial difficulties with the system, primarily related to the unfamiliarity with teleportation mechanics, resulting in unexpected collisions with virtual objects. A participant reported *"Only when teleporting, there it was confusing when you're suddenly standing right in front of a wall"* (p. 25). When asked in further detail about their initial interactions, a minority reported issues operating controllers, orienting within the VR environment, or using tools within the scenario, for example, one participant said *"...that you suddenly found yourself in a wall or in the fuse box"* (p.17). A couple of participants experienced dizziness, attributing it to the confined physical classroom space available for VR interaction, one mentioned *"I had difficulties setting up the play area (p. 13)."*

The analysis revealed the following prominent themes:

**Overall Satisfaction with VR-Based Training:** *Despite these challenges, an overwhelming amount of participants expressed satisfaction with the VR-based companion training. [This finding contributes to Chapter 7, subsection 7.3: Cognitive and Emotional Support.]* The realism of the learning scenarios was highlighted, which also contributed to user satisfaction, with participants noting the benefit of practicing complex topics in VR before real-world application. A participant said “for preparing for the final apprenticeship exam because you have to master exactly these topics well” (p. 27). *The simulation’s close alignment with real-world movements was appreciated for facilitating effective learning [This finding contributes to Chapter 7, subsection 7.3: Collaborative and Relational Design.]* One participant emphasized “...that it was good to be able to practice such topics in VR first and only then in reality.. it is much safer that way (p. 9). Another participant pointed out “It’s good that you make similar movements with the controllers as you do in real life: that’s why you learn it quickly” (p. 9).

**High Presence and Comfort:** Participants also reported a sense of high presence. Some reported comfort with wearing HMD for example, one said “I almost forgot I am wearing it” (p. 13).

**Interest in Integrating VR into Curriculum:** Most of the participants expressed interest in incorporating VR-based companion training into their curriculum, citing practical relevance, safety, and the ability to grasp complex concepts as driving factors. One participant said “...because I would have understood many things more easily. One remembers concepts better than only if taught theoretically” (p. 10).” Another participant reported “... because this exercise is very instructive, and I can concentrate better than in normal lessons” (p. 4).”

**Practical Relevance and Enjoyable Learning:** *Engaging in VR training allows individuals to perceive complex connections and gain insight into the bigger picture [This finding contributes to Chapter 7, subsection 7.3: User Autonomy and Control.]* In the absence of such immersive experiences, practical knowledge often remains isolated. A handful of participants expressed that the system’s practical relevance and enjoyable nature motivate them to embrace this approach. They mentioned “you can’t break anything” (p. 17) and “I also think it’s good that you can try things out before you do them in reality.” (p. 12). *Suggestions emerged for integrating VR into vocational education, with a proposed model of alternating theory and VR practice [This finding contributes to Chapter 7, subsection 7.3: Personalization and Adaptability.]* A participant said “I would do it by scheduling the theory lessons beforehand, for example, two weeks; and then practice with VR for maybe a week; (so that) you can then directly apply what you have learned in theory; then you remember things much better” (p. 10). The potential benefits of VR-based training included improved memory retention, a better

understanding of tasks, and enhanced focus. As a participant said “*One is really focused and actively dealing with the topic*” (p. 8).

**Anticipated Challenges and Recommendations:** Anticipated challenges included concerns about technology acceptance, teacher adaptation, monitoring student progress, and costs. Some participants feared diminished dedication to traditional theory and hands-on learning. Addressing this, recommendations were made to stream VR content to screens or use introductory videos and tutorials, provide tutorials, and involve teachers during training. *Participants stressed the importance of instructor involvement during VR practice for guidance and technical support [This finding contributes to chapter:guidelines: Collaborative and Relational Design.]* A contact person was deemed essential for addressing questions and maintaining a structured learning environment. The consensus was that trainers’ presence ensured effective training sessions, fostering focus and discipline among learners. A participant mentioned “*It certainly doesn’t work without a teacher; they always have to be there when practicing, otherwise it would be far too unsettled (and noisy in the class)*” (p. 20).

#### **Case study 2 - Spatial VR Training for Healthcare and Emergency Responders**

This work aimed to create and evaluate VR-based companion training scenarios for healthcare and emergency response personnel, specifically focusing on spatial navigation and evacuation training. The comprehensive case study involved conducting a literature review centered on VR training for first responders, developing outlines for training scenarios, and ultimately implementing and assessing these scenarios with medical professionals. Following a methodology similar to Case Study 1, the project placed a strong emphasis on understanding users’ subjective experiences, their confidence in using the VR training companion system, and identifying skills and activities suitable for VR support. VR-based scenarios were developed to measure training effectiveness: designed to improve spatial orientation skills during hospital evacuations, which was then compared to a printed map-based training approach.

**Study Design:** To compare learning outcomes across two training methodologies effectively, participants were randomly assigned to either a VR companion scenario or a printed materials condition. The choice of the printed media condition stemmed from its widespread usage, enabling self-guided practice regardless of time and location. Each group was provided with 8 minutes of training time for the task. After the training phase, participants carried out the task in an authentic environment to assess their performance. At the study’s commencement, participants received an explanation about the experiment’s objectives and its timeline, following which they granted their consent to partake. Every participant was allocated a distinctive ID and advised against sharing their experience with others. The individuals were randomly divided into either the VR or non-VR groups, receiving instructions on navigating the VR system before embarking

on an 8-minute training session. Subsequent to the task, participants underwent brief interviews aimed at capturing their personal perceptions of the experience.

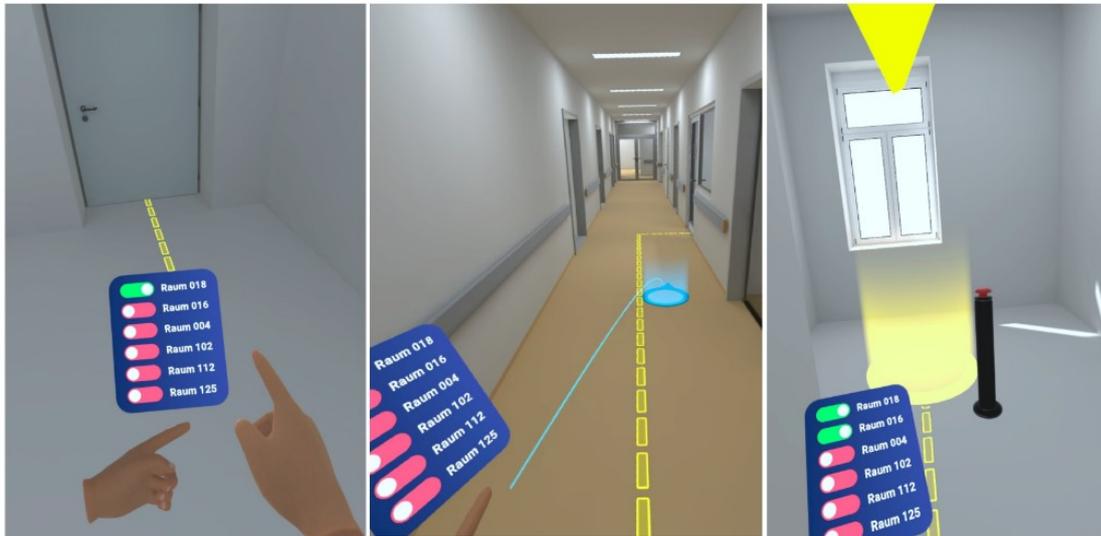


Figure 3.3: The view of the user when starting the scenario (left), user’s view of the hallway with pointing teleport (middle), and a room to be marked as visited (right).



Figure 3.4: The path leading to the first room (016) in the VR (left) and the real hallway (right).

**Task:** The spatial orientation scenario showcased a virtual representation of SIM Campus in Eisenerz, Styria, Austria<sup>7</sup>. The virtual scenario commenced within room

<sup>7</sup><https://www.simcampus.eu/> – Accessed July 2022

018 on the ground floor, mirroring the actual starting point as depicted in Figure 3.4. The VR scenario aimed to closely replicate the building's attributes such as flooring, doors, windows, room numbers, and descriptions, though room furnishings were omitted. Participants were tasked with memorizing a sequential route within a building comprising five rooms labeled 016, 004, 102, 112, and 125. Notably, rooms numbered with a prefix of 0 were situated on the ground floor, while those bearing a prefix of 1 were positioned on the first floor. However, explicit instructions on how to memorize the route were intentionally withheld. The primary objective was to visit the designated rooms in the specified sequence, tracing the dashed pathway illustrated on the map or within the VR simulation (as depicted in Figure 3.3), all the while adhering to the route without adopting shortcuts or diversions. It's noteworthy that none of the participants had previously visited the building. Participants were required to sequentially visit the five designated rooms, with the list of rooms displayed on the left controller, featuring green and red checkmarks denoting visited rooms. Participants were advised to maintain their regular walking pace, refraining from running or walking excessively fast. Movement within the scenario could be executed by walking or teleportation, guided by a yellow dashed line traced across the floor. Upon entering a room from the list, a yellow circle appeared on the floor, accompanied by a buzzer indicating the room has been visited. The final buzzer prompted a "restart" command, transporting the participant back to the initial starting position. The yellow dashed line can be turned on and off by pressing the joystick on the right controller. In both the VR simulation and the map, each group was granted an 8-minute period to prepare for the task. During the real-world tasks, an observer recorded participants' movements within the building, mapping their routes onto a paper representation of the premises and documenting relevant variables.

**Participants:** 20 nursing students from FH Sankt Pölten<sup>8</sup> and Akademie für Gesundheitsberufe Wien<sup>9</sup> participated in the study. Those who indicated their interest registered via an online form. Participants who experienced VR training had an average age of around 33.10 years (SD = 8.99). Those without VR training had an average age of approximately 34.05 years (SD = 9.65). The overall average age for all participants was approximately 33.58 years (SD = 9.22). Among VR-trained participants, 85.00% were female and 15.00% were male, while in the no VR group, 95.24% were female and 4.76% were male. Interviews were conducted with seven participants who had undergone training using the VR simulation. In order to encompass a broad spectrum of responses, including those from individuals who exhibited better performance in terms of time efficiency, and error rates, as well as those who encountered challenges during the task. Additionally, participants with performance levels approximating the mean were included in the interview pool. The interviews were analyzed using the qualitative content analysis method as proposed by Mayring [May00].

---

<sup>8</sup><https://www.fhstp.ac.at/de> – Accessed July 2022

<sup>9</sup><https://gesundheit-studium.at/> – Accessed July 2022

**Results:** Performance variation between VR and map-based learning to navigate was characterized by VR companion participants emphasizing visual cues over room numbers, finding the VR experience immersive. In contrast, map-based learners relied more on room numbers for navigation. While VR companion offered benefits such as increased engagement, challenges like motion sickness needed to be addressed in the design and implementation of VR scenarios. Overall, the complexities of orientation and locomotion revealed the need for further research.

**Attention and Focus on Environmental Cues:** Through our observations and follow-up interviews, participants within the no VR group displayed a heightened attentiveness toward room numbers, while their counterparts in the VR group directed their focus toward visual cues encompassing glass doors, the door count between rooms, and the room's positioning relative to corners. Notably, the significance of room numbers was notably diminished within the VR group compared to the no VR group.

**Emphasis on Visual Cues in VR Training:** VR companion group emphasized on visual cues, as evidenced by their attentiveness towards the glass door situated at the hallway's end and the glass window positioned to the right. Furthermore, the majority of participants conveyed a favorable assessment of the VR training experience, citing attributes such as realism, novelty, enhancement of procedural skills, and heightened focus as the pivotal factors contributing to their positive appraisal. One participant said *"Remembering the surroundings is much better when I experience it directly instead of through pictures and videos"* (p. 3). Some pointed out *"more detailed visual cues would have been helpful"*(p. 9, 15).

**Motion Sickness and Disorientation:** In terms of the motion sickness encountered during VR training, the findings indicate that most participants did not encounter significant issues related to nausea, dizziness, or fatigue. In general, approximately 20% of the participants reported moderate to intense feelings of disorientation, while another 20% reported very intense or extreme sensations of disorientation. This suggests that these challenges could potentially arise from the specific scenario design and the method of movement within the virtual space.

#### Case study 3 - Medical Trolley Scenario

The study aimed to compare the effectiveness of VR training with printed materials in assisting medical professionals in learning the placement of medical instruments on a trolley for intubation. Participants in the VR companion group underwent training using a virtual representation of the medical trolley and its contents. In the printed materials group, participants received printed materials, including written lists and images of the instruments and their correct layout on the medical trolley.

**Study Design:** The study commenced by obtaining informed consent and registering participants with unique IDs. Subsequently, participants were escorted to a waiting area, where they were briefed on the study's procedure, timeline, and objectives. To optimize resource utilization and minimize wait times, the experiment was conducted simultaneously with the spatial orientation scenario. Participants were randomly assigned to either the VR or no-VR group for different experiments. VR group participants were acquainted with the VR headset and scenario usage, while the no-VR group received printed instructions. Both groups were allocated an 8-minute preparation period. Afterward, they proceeded to the room containing the actual trolley. The researcher reiterated task steps and addressed questions before participants performed the task, with no time limit. Brief interviews were conducted with participants after the task to gather insights.



Figure 3.5: The real medical trolley (left), the virtual trolley and the whole setup with buttons (middle), and a detailed picture of the top of the trolley (right).

**Task:** The VR companion simulation included a room featuring a medical trolley that accurately replicated the trolley used in the experiment, as depicted in Figure 3.5. The objects within the simulation were positioned in the same locations as those on the real trolley. Within the simulation, three buttons—labeled "stencil," "check," and "reset"—were situated next to the trolley. The "stencil" button displayed a diagram illustrating the intubation instruments and their placements. Notably, the oxygen mask was positioned within a basket on the left side of the trolley, while other instruments were stored within its drawers. Participants were tasked with memorizing the locations of 11 medical instruments required for intubation. Participants had to locate, pick up, and position items onto the stencil using controllers. A counter kept track of the items placed. The "check" button, initially grey, turned red when an error was detected and green when everything was correct. The "stencil" button could activate or deactivate the background stencil, as seen in Figure 3.6. Users had the option to practice without the stencil, and the "reset" button restored the trolley to its original configuration by clearing



Figure 3.6: Participant training in VR (left), participant's view of the trolley (middle), the buttons next to the trolley (right).

items and returning them to their initial positions. During the task, a researcher recorded task completion time and requested hints, and errors using a protocol. After completing the task, a photograph of the top of the medical trolley was taken for documentation purposes and for further investigation during the interview.

**Participants:** The study was conducted with 21 participants, including nursing school students, medical students, and nursing school teachers. Nursing students of FH Sankt Pölten and Akademie für Gesundheitsberufe Wien were offered participation in the study. They were drawn from the identical pool of participants who were recruited for Case Study 2. Following the medical trolley task, 9 participants who underwent VR training were invited to partake in semi-structured interviews. The selection was guided by task performance, encompassing three participants who excelled, three who faced challenges, and three who performed at an average level. The interviews underwent analysis through the qualitative content analysis method proposed by Mayring [May00]. The transcription procedure was uniformly implemented for all interview records. A collective effort of three researchers was employed for the comprehensive analysis of the interview data. Subsequently, each interview's data categorization underwent a re-evaluation by at least one researcher to arrive at the definitive categorization.

**Results:** The following themes have surfaced from the analysis of interview data:

**Ease of Use and User-Friendly Nature:** The majority of participants expressed ease and comfort in using VR companion, highlighting its user-friendly nature and quick learning curve. Within the VR group, the feedback regarding the medical trolley training scenario was predominantly positive, with the majority of participants expressing

satisfaction. Nevertheless, a subset of participants faced challenges due to reduced accessibility, potentially linked to visual blurriness, as certain individuals couldn't wear glasses during the training.

**Interaction and Learning Experience:** The majority of participants found the interaction to be straightforward, with a few expressing appreciation for the haptic sensations associated with object manipulation, as opposed to mere textual learning. Predominantly, positive feedback stemmed from the well-structured introductory tutorial, aiding comprehension of interactions and fostering familiarity with the VR companion environment. However, a notable concern pertained to the scenario's interaction "*Once I got stuck with the hand in the drawers and also accidentally teleported myself*" (p. 2). Additionally, few participants encountered challenges involving fine motor skills while placing instruments on the trolley (p. 12, 16). Emphasis was placed on the link between theoretical and practical knowledge, with the sentiment that such connections imbued confidence, as a participant reported "*You can gain confidence in situations when theoretically learned, and then done practically in VR, then in real*" (p. 4). Another salient observation highlighted the significance of movement congruence during task preparation and execution. A participant said "*I was well prepared (for the exercise), I've seen it before the exercise, it was then the same moves again*" (p. 6). *Suggestions for enhancing the training included incorporating greater variety and realism [This finding contributes to Chapter 7, subsection 7.3: Cognitive and Emotional Support.]* This could entail minor adjustments to the initial object placement to emulate real-world imperfections.

**Integration of VR Training:** In terms of integrating VR companion training, the majority of the participants advocated for its inclusion in the vocational school's curriculum. This integration could manifest through concentrated modules or regular sessions featuring VR training. The virtue of practicing in VR prior to real-world application was highlighted, with the concept of virtually enacting emergency scenarios and subsequently replicating them, in reality. A participant said "*Re-enact emergency situations and then again in real life, i.e. first experience them virtually instead of just explaining them*" (p. 8)." The most frequently cited advantages encompassed improved retention, the authenticity of VR training, and the absence of risk or fear. A participant reported "*Practical exercise helps me more than the theory*" (p. 6). Another participant said "*The repetition makes it totally memorable. It's really not the real world, but very close. You are not afraid of making mistakes, trying things out, and training*" (p. 12). The main concern regarding the use of VR in education is the level of acceptance among trainers and their knowledge of the technology which is a premise for successful integration and application of VR in the curriculum. The majority mentioned that the trainers should explain how the system works and then supervise the training, and do training evaluation. A participant said "*Explain - what will happen, explain tasks, clarify questions about VR and be available*" (p. 12). The proposition emerged that VR supervision could be facilitated by a virtual representation of the trainer or through the trainer's involvement in a multiplayer mode.

### 3.1.3 Discussion

Overall, users and trainers engaged in the experiments embraced the training with positive sentiment. Realism, novelty, and fun emerged as primary positives across all groups, with fun holding particular significance for apprentices. Better focus in the VR environment was consistently cited by all groups, with participants highlighting the exclusion of external distractions, leading to a heightened focus on the task. Initial challenges in steering and navigation abated with time and effective tutorials. Overcoming these challenges hinged on comprehensive guidance, clear goal explanations, and adequate support during training. Participants suggested expanding scenarios and incorporating varied difficulty levels while acknowledging the known limitation of haptic feedback in existing VR HMD systems. In terms of technology acceptance, all scenarios were deemed fun. The VR environment was perceived as closely resembling to reality, a critical factor contributing to user acceptance [LBR<sup>+</sup>15]. The electricians' scenario received slightly less positive feedback regarding ease of use, possibly attributed to participants from diverse specializations requiring more time to grasp the training's background.

Participants in spatial orientation and medical trolley scenarios trained in isolated, controlled surroundings, receiving focused attention from a trainer (a researcher overseeing the training). Conversely, the electricians' scenario group practiced in settings like classrooms or breaks, exposing them to more environmental distractions and noise. Regarding user experience with VR conditions, all scenarios were perceived as clear, efficient, and highly engaging. Distinctions surfaced particularly in perceptions of complexity, ease, intrusiveness, and supportiveness of training. The spatial orientation scenario in Case Study 2 appeared more complex and intrusive, while the medical trolley scenario in Case Study 3 gathered praise for its supportiveness and excitement. All movements could be seamlessly executed through familiar actions mirroring those in the real world, such as walking, rotating, and interacting with objects by grabbing and placing them. Despite teleportation being the recommended mode of movement to alleviate cybersickness [GGBZ21, TPB<sup>+</sup>17], it presented challenges in scenarios involving teleportation, leading to higher difficulties and disorientation, as indicated by the results. Concern was echoed in interviews, where teleportation difficulties were cited in both electricians' and spatial orientation scenarios, likely contributing to these variations. One potential explanation could be attributed to the frequency of teleportation required for successfully completing the scenario. Participants noted the uniformity in the visual design of the scenario, underlining the need for a greater variety of visual cues. For Case Study 2, a participant criticized the guidance line leading to the next room, suggesting that it might inadvertently encourage participants to follow the path without fully engaging in the route's comprehension and memorization. The findings indicate a relative mismatch between VR training and tasks involving spatial orientation. However, further investigation into this matter is needed, as our results partially diverge from the conclusions drawn in the study by König et al. (2020) [KKC<sup>+</sup>20]. Some participants expressed a preference for authentic walking over teleporting, yet implementing this in cases where virtual distances surpass available training space poses challenges. Moreover,

Table 3.1: Benefits and Challenges of VR Training.

Overview		
Parameters	Opportunities	Challenges
Accessibility	VR training provides a safe and accessible way to practice at one's own pace with more repetitions, leading to increased confidence and less fear of mistakes. Cybersickness is rare.	While individual differences or cybersickness can still be a concern, providing good tutorials, support, and familiarity with VR beforehand can help prevent these issues.
Learning	VR training offers better focus and fewer distractions and is effective for training procedures and complex scenarios that require the application of knowledge. The similarity between the movements in VR and real life promotes better recall.	There is a possibility that risks may not be taken as seriously in VR training scenarios, and trainers may have difficulty learning how to use the system in the classroom.
Acceptance	The majority of participants (over 70%) were satisfied with the VR training, over 85% found it fun, and all but one said they could imagine having similar training in the future. High presence, quality, and low cybersickness indicate high acceptance [Dav89].	It may be challenging to find motivated trainers and directors at vocational schools who are willing to implement VR training and potentially participate as experts in the development process.
Motivation to Use	VR training is enjoyable, novel, and practical, requiring only HMDs and scenarios. There is a low fear of making mistakes, and a safe space is provided for practice.	Implementing VR training requires extra organizational effort for vocational schools and trainers, along with additional costs for equipment and scenario development and maintenance. Haptic feedback precision may be insufficient for some tasks, and high realism and detailed visual cues are necessary.

the medical trolley and electricians' scenarios gathered greater overall satisfaction than the spatial orientation scenario. These outcomes align with the research of Renganayagalu et al. (2021) and Górski et al. (2021), who identified procedural skills training as the most prevalent and fitting content for VR-based training [RMN21, GGBZ21]. Even though it is possible to offer individual learning scenarios without the guidance of a trainer, our results support the findings of Popovici and Marhan (2008) and Schwarz et al. (2020) suggesting that VR training should be always supervised [PM08, SRKS20]. A substantial majority expressed enthusiasm for integrating VR training into vocational schools, especially for complex procedure practice in a safe virtual environment before real-world application. Trainers should initiate, explain goals, be present during training, and provide feedback. Interacting with the broader class through streaming was also suggested. Integrating such a training system could face challenges from potential trainer disinterest or lack of knowledge and substantial costs, maintenance, and technical hurdles.

The insights derived from the analysis of the three case studies allow us to address the two research questions initially posed as follows:

**RQ1:** The findings from the case studies consistently highlight a strong sense of presence, indicating that the VR companion is closely aligned with reality, a crucial factor influencing user acceptance. However, certain technical elements within the training scenario, such as the design of the measuring device, don't accurately mirror reality. In terms of user experience, the training scenarios garnered positive evaluations, being perceived as engaging, captivating, and innovative. Participants found the VR-based companion training to be enjoyable, with some characterizing it as an entirely novel and favorable encounter. The interaction and navigation within the VR training environment garnered praise for being intuitive, although some participants initially encountered challenges. Most participants found the virtual environment easy to navigate and comfortable to use, revealing a substantial level of acceptance for VR-based learning within professional training. Nonetheless, the adoption of teleportation for movement exhibited problems in scenarios requiring more extensive movement, leading to instances of disorientation. On the whole, the study highlighted that procedural skills were particularly well-suited for VR training. However, further investigation is warranted to ascertain the efficacy of VR training for tasks that involve spatial orientation.

The limitation of haptic feedback precision in widely used VR systems is acknowledged, rendering it inadequate for intricate activities necessitating precise motor control. These findings come as no surprise, considering that the limitations of haptic feedback in widely employed VR systems are well-established [PLS<sup>+</sup>21]. Nevertheless, VR-based companion training proves particularly effective for comprehending intricate scenarios and refining complex skills, as it facilitates an enhanced grasp of interconnections and broader contexts. Study participants also reported heightened concentration while using VR and expressed a preference for trainer guidance and support. Our work implies that supervisory oversight remains crucial for VR training, even though proficient users might necessitate reduced assistance. Trainers recommended interactive tutorials and projecting scenario content on large screens to alleviate their workload. However, the guardian

system, which visually outlines the safe area, perplexed some participants.

Enforcing mandatory VR companion training might not be suitable, considering some participants' discomfort. Nevertheless, our work indicates that VR training can complement traditional methods effectively, albeit not replace real-world practice. Schwarz et al. (2020) also affirm that VR training is meant to complement traditional training methods [SRKS20]. Additionally, it was highlighted that VR-based training serves as a valuable supplement and cannot serve as a complete substitute for real-world practice, a notion echoed in the study by Bracq et al. (2019)[BMA<sup>+</sup>19]. The challenge lies in the expense and creation of VR training content and equipment. Implementing VR training in vocational schools, with shared scenarios developed by higher institutions, could mitigate costs. Diversifying training content across difficulty levels and adapting it to different knowledge tiers is advisable. Enhancing scenario flexibility and scalability contributes to a more authentic training encounter. [MPGK15] also emphasize the significance of flexibility and scalability. Collaboration with experts is crucial for content development. Thorough briefing, ongoing support, and trainer feedback are imperative for successful integration. Overall, the study highlights that VR-based learning can enhance education and training, while individual preferences and comfort levels should guide its introduction. A concise overview of the primary findings related to the opportunities and challenges associated with RQ1 is presented below in Table 3.1.

**RQ2:** Guidelines were created based on the challenges and opportunities that were previously discussed:

1. When devising scenarios for VR companion training, it is imperative to adopt a user-centered approach and involve experts and stakeholders throughout the development process. This collaborative effort ensures the relevance and accuracy of the learning content. Early involvement of prospective users in testing can help unveil potential issues from their perspective.
2. An effective training scenario should incorporate multiple levels of difficulty to offer an optimal learning experience that caters to all users' motivation and skill levels. Striking a balance between challenges and attainability is vital. To enhance realism and the ability to learn from errors, the scenario should incorporate a direct feedback mechanism.
3. Employing cutting-edge technology is pivotal for the training system's success, as it contributes to an immersive user experience and a strong sense of presence. Realism and detailed visual cues play a crucial role in engaging learners effectively.
4. Single-user VR training holds particular promise for developing procedural skills, especially in the context of safety-critical procedures. Complex scenarios that require the integration of diverse knowledge and its practical application are exceptionally well-suited for leveraging VR technology's advantages. Active interaction with the virtual environment fosters effective learning.

5. During the initial stages of VR training, supervision by a trainer is highly recommended to offer guidance and assistance. Starting with an introduction to the technology and setting clear training goals is essential. Throughout the training, users should have access to help when facing challenges and receive comprehensive feedback upon completion. While trainers can provide supervision, the VR environment can also facilitate group exercises for shared learning experiences. Advanced users can benefit from more independent and frequent practice.
6. To mitigate potential challenges during initial VR training experiences, users should have the opportunity to familiarize themselves with the virtual environment beforehand. This proactive approach can help prevent issues like cybersickness and reduce stress and frustration levels.
7. Prior to integrating VR training into educational curricula, it's essential to establish a comprehensive guide encompassing the use of technology, including both hardware and software. Utilizing video tutorials can be a time-efficient approach, saving trainers from repeatedly explaining scenarios.
8. Clearly defining the responsibilities related to the maintenance of VR equipment is crucial to prevent technical complications and ensure a seamless training experience.
9. Successful integration of VR training requires a dedicated place within the curriculum. While it should not entirely replace existing practical exercises, the specific mode of integration should be left to the discretion of trainers and vocational schools to align with their unique contexts.
10. To ensure the efficiency and effectiveness of training, trainers themselves should possess expert proficiency in using VR technology. They should be capable of offering assistance when needed. The choice between training domain-knowledgeable trainers or engaging external experts depends on the nature of the training, its contextual factors, and the educational institution's decision-making process.

**Limitations** This study exclusively examines the immediate outcomes resulting from the utilization of single-user VR companion training prototypes, precluding any inferences regarding the lasting impact of similar single-user VR training solutions. We acknowledge that differences in interactivity may have influenced the level of engagement independent of the characteristics of the companion. Future studies may benefit from the inclusion of additional baseline conditions to further validate findings. Consequently, further research is imperative to explore the effects over an extended timeframe. The investigation was conducted within the specific context of vocational education, implying that the findings might not be generalizable to other educational frameworks. Instances of participants disregarding instructions to employ their assigned IDs when initiating the scenarios led to complications in HMD calibration and rendered scenario logging data unsuitable for study purposes. Additionally, compliance with COVID-19 regulations mandating the use of FFP2 masks may have influenced the comfort of the VR training system and contributed to issues with fogged glasses.

#### 3.1.4 Conclusion and Future Work

Our research delved into the advantages and impediments associated with the utilization of VR-based companion for single-user training in the context of professional education. The investigation encompassed the assessment of three distinct training scenarios involving apprentices and nurses. Employing a combination of workshops, interviews, and observations, the study sought to evaluate the efficacy of VR-based training. The findings unveiled that VR training affords learners the capacity to engage at their own pace and with repetition, thereby fostering increased self-assurance and diminished stress. Nevertheless, individual disparities and cybersickness emerged as potential challenges, which can be mitigated through robust tutorials and requisite support. The study further unveiled that VR training holds the potential to enhance concentration and proficiency in complex scenarios; however, the incorporation of error feedback is vital to sustain the seriousness of learners' engagement. Furthermore, the study revealed that embedding VR training within educational frameworks demands organizational commitment and additional expenditure. Nevertheless, the research highlighted an elevated degree of acceptance among users, accompanied by constructive feedback, indicating the promising prospects of VR training in the realm of professional education. Adopting a user-centric approach during the development and testing of VR training scenarios emerged as a pivotal consideration to cater to diverse user cohorts. Furthermore, trainers must possess a comprehensive understanding of the technology to offer proficient guidance and assistance during training sessions. The insights and recommendations arising from this study are poised to benefit organizations contemplating the integration of VR training into their educational paradigms. Further research is warranted to explore its potential in other spheres, expanding beyond professional education. A longitudinal exploration of VR training's lasting effectiveness, encompassing changes in learning outcomes and knowledge retention across varying skill levels, is pivotal. The evolution of VR solutions could encompass collaborative and gamification approaches, alongside the integration of AI-based mechanisms for tailoring experiences to users' proficiency levels. Enhanced haptic feedback and novel interaction methods, such as sensor gloves, hold the promise of augmenting the effectiveness of VR companion training interventions. Also, a detailed evaluation of the proposed guidelines could be conducted in the future.

## 3.2 Skillab Companion

This chapter is based on our following publication:

#### Publication

Shahu, A., Dorfbauer, S., Wintersberger, P., & Michahelles, F. (2023, August). Skillab-A Multimodal Augmented Reality Environment for Learning Manual Tasks. In IFIP Conference on Human-Computer Interaction (pp. 588-607). Cham: Springer Nature Switzerland.

Augmented reality (AR) can be considered as an interactive, reality-based display environment that integrates actual and computer-based scenes and images to create a seamless yet improved perspective of the world [TD92, Bar15, Azu97, SDG17]. Recent developments in AR have a great deal of promise to be influential in many industries, particularly education and training. Chang indicates that various researchers have proposed that AR can help learners improve their educational realism-based practices and increase their eagerness to learn [CMM10]. Implementing AR in education and training is still quite difficult due to problems with its integration with conventional learning methods, the expense of developing and maintaining the AR system, and a general aversion to new technologies [Lee12].

Pan and colleagues investigated how a virtual learning environment (VLE) could be used in education to facilitate collaboration on learning, training, and entertainment [PCY<sup>+</sup>06]. The findings showed that the suggested VLE could improve, inspire, and stimulate learners' comprehension of certain events that the conventional learning strategy could not readily do. Under a virtually enjoyable environment, users can learn quickly and with interest. Similarly, AR can be used to expand the user's range of understanding while simultaneously presenting facts and information in a real-world context [KRC11]. Wang and colleagues examined the most recent advances and innovations in the field of AR technologies in formal and informal learning [WCB<sup>+</sup>18]. They categorized the benefits of adopting AR in training and education into the following three groups: a) Learner outcomes—improved academic performance, higher drive for learning, better comprehension, a good attitude toward learning, and increased satisfaction; b) Pedagogical contributions and interactions—improved enjoyment, boosted learner engagement, encouraged curiosity, offered chances for collaboration and encouraged self-learning; and c) Other—enables the visualization of oblique or abstract ideas, is simple for learners to use, and requires less material. Similar research has been done by Tang, but the effectiveness of learning compared to conventional methods has not been thoroughly examined [TAL18].

With the recent COVID-19 pandemic, when people have limited access to and contact with in-person learning facilities, systems based on AR offer the flexibility to pick up new skills without depending on an expert. This makes learning increasingly hands-free and immersive. Users are able to do the activity using both hands while still paying attention to the task instructions. This technology has the potential to offer audio and visual feedback at the appropriate points in the learning process. Also, the tangibility dimension is necessary to fully appreciate skill-building in digital systems. For example, in order to simulate the sensation of blending paint with a finger, [SRP<sup>+</sup>18] built a special tangible display that resembles liquid for mobile, digital color mixing. EMS has been used to collaborate on the creation of visual art pieces. Authors used EMS to simulate the process of painting, allowing the audience to direct the artist's brushstrokes [CLFH18].

To contribute to the field of AR education and learning, we introduce Skillab Companion, an “AR-based craft-work learning system”. It enables learners to follow a step-by-step tutorial for learning and developing floor lamination skills while using real-world tools

and objects to promote learning and playful experiences. Utilizing computer vision to examine their progress, Skillab uses AR to deliver in-situ feedback. Using Skillab, we also demonstrate how muscle actuation methods can be leveraged to offer haptic assistance for guiding motoric action. We used a simple hammering demonstration to gauge people's initial impressions of on-body actuation technology. Thus, our multi-modal system includes visual, auditory, and haptic components in its distinct learning processes. We compared it to the printed manuals as many toolkits on the market still come with a lengthy and complex printed manual of instructions. To learn the skill, users are expected to read through the illustrated instruction manual and make sense of it. In order to further enhance our AR-based solution, we compared the advantages and disadvantages of print instructions with AR. Our research questions are exploratory in nature:

- **RQ1:**What are the key advantages and challenges of the "AR-based craft-work learning system" approach to skill-building compared to traditional instructions?
- **RQ2:**What aspects of the Skillab companion seem to assist and encourage learning?
- **RQ3:**What impact do multi-modal feedback interactions have on the user experience?

To evaluate Skillab, we implemented floor lamination as the craft in a between-group study with 20 participants. While one group followed traditional paper instructions, the other group completed the tutorial using the Skillab application. We calculated multiple performance indicators and discovered that participants using Skillab made fewer errors when re-creating the task. Participants using Skillab reported a better user experience, based on the evaluation of video recordings and a post-experiment survey. However, some participants reported issues with the Skillab tutorial and provided valuable feedback for improving the system.

We contribute with a) the concept for a novel AR-based application incorporating muscle actuation technology to learn craft-work; The research's novelty resides in its ability to deliver muscle actuation feedback without sacrificing user agency; b) user study results that show how users can interact with our application and what kind of feedback was found to be useful; c) insights on how people can be encouraged and inspired to learn new skills by utilizing immersive environments. As a result of their improved user experience and engagement with the AR-based system, our participants expressed a greater interest in using it to learn new skills.

#### 3.2.1 Related Work

Through immersive experiences and multi-modal feedback including muscle actuation, our work aims to teach users how to laminate a floor. We draw upon the following theoretical constructs [KNB<sup>+</sup>19]:

**Structure-Behavior-Function framework (SBF)** : SBF divides complex systems into three categories: structure, which consists of the fundamental parts and their connections; behavior, which describes how each element of the structure behaves both individually and collectively; and function, which describes the goal of the system as a whole or its parts [HSML07]. With this three-pronged strategy, the SBF framework may methodically draw users' attention to essential elements of the craftwork and assist them in dissecting and visualizing the relationships that are often difficult to understand [GVR<sup>+</sup>10]. The SBF framework is put into practice by Skillab companion. It explains each component's role in relation to the others clearly and step by step.

**Constructionism** : According to this learning theory, learning occurs "felicitously" when learners create and tinker with tangible objects [PH91, Sta05]. We employed AR technology because it allows users to interact with real tools and objects.

**Scaffolding** : Scaffolding can come in a variety of ways, from suggestions for task breakdowns to coaching and prompts, all of which aid learners in completing work that might otherwise be too difficult [QRD<sup>+</sup>18]. We offered users AR-mediated scaffolds that make conceptual understanding and craft design simpler.

### Skill-building and AR

The most common method of learning a craft is through an apprenticeship, which involves observing an expert craftsperson and getting feedback as the skills are repeatedly practiced [Gam01]. Undoubtedly, having an expert present provides for professional demonstration and personalized comments. Nevertheless, the current traditional approach has a number of drawbacks. The apprentice has a high level of dependence on the instructor because the majority of learning is done through observation [CBN18]. A skilled practitioner might have to repeat something multiple times because a learner might not be able to comprehend and remember it [OZ10]. The COVID-19 pandemic has shown that physical presence is not always possible. In the conventional learning process, it takes a while for a student to finish each task or activity. This makes the actual learning process dull and uninteresting. The traditional method's constrained viewing angle can lead to learning difficulties. Additionally, learners find it difficult to visualize bodily motion in its entirety. Nawahdah and Inoue created a system that interactively modifies the learner's point of view and displays the instructor's mobility in a 3D virtual environment, suggesting that the system increases the effectiveness of learning [NI12]. Anderson introduced a system that shows the difference between learners' motion and instructed motion by employing an augmented reality mirror to teach full-body motion. When compared to traditional video learning, the system performed better in terms of learner performance [AGMF13].

Iyobe described and assessed a mobile virtual traditional crafting presentation system that consists of a Content Browsing Mobile application and a content management web application [IIM<sup>+</sup>16]. The former offers a wide range of conventional craft information and a strong sense of immersion through AR content. The latter controls how the Content

Browsing Mobile Application handles information on traditional crafts and techniques. Hiyama approached with the intention of skill transmission and preservation, but in a more integrated manner using a variety of sensors, giving the numerical tacit knowledge of professionals a closer look [HOM<sup>+</sup>13]. They developed a comprehensive framework for artisanship's digital preservation. For Kamisuki (Japanese traditional craftworks), they employed projection-based augmented reality displays that superimposed expert motion on the wooden tool. The quality of the paper produced by learners and the performance of the coaching expert were both enhanced by quantized motion data presentation. Thus, interactive simulation systems show potential in improving learners' conceptual understandings [ZA03, RIP99]. Drawing from all of these strategies, Skillab stands out due to its emphasis on user experience, muscle actuation technology, and step-by-step real-time scaffolding.

#### Electrical Muscle Stimulation

EMS mimics the body's natural electrical impulses by introducing a small electrical current into the muscles, which can cause muscle contraction and, as a result, movement of the body [KIMR18, PDR16]. A calibration procedure is necessary to ensure pain-free functioning because the amount of force needed to activate a muscle varies between body parts and users [KAH18]. Due to the fact that EMS directly writes to the muscles creating motor movements, it can offer a variety of unique interaction scenarios. It can be used to offer haptic feedback [LB20] by varying stimulus parameters (i.e., amplitudes, pulse widths, frequencies). In an augmented reality tennis game, Jain and colleagues used EMS on the wrist muscles to simulate the impact of a ball striking a racket [JSB17]. Impacto used EMS in conjunction with tactile feedback (a solenoid tapping the skin) to replicate the feeling of striking or being hit in VR boxing [LIB15]. Lopes showcased a mobile device that uses EMS to provide mid-air force feedback for Mixed Reality games and experiences [LYIB18]. Their solution was centered on the HoloLens headset, which frees users' hands and enables them to interact fully with both virtual and real-world objects, including furniture, appliances, and props. According to Faltalous, EMS is effective in eliciting a prompt response while enabling users to concentrate on their task, as demonstrated by the reduced over-crossed distance and improved reaction time compared to visual and auditory feedback [FNGS20]. Before any physical contact with objects occurs, Lopes has used EMS to build affordances for objects that do not express them adequately otherwise [LJB15a]. Similarly, EMS has been used to provide force feedback for walls and heavy objects in virtual reality [LYC<sup>+</sup>17a], to improve human reaction speed [KNL19a], and to control the up- and downward movement of another human's arm [KST15].

EMS was also used for assistance and training. Ebisu and team, for instance, regulated users' movements by actuating both their arms and legs to teach users how to play percussion instruments [EHO18]. Even though there were no professional percussionists present, the students were nevertheless able to pick up the rhythm. One hand's beat and the rhythm of both hands can be taught to students at the same time. It was possible to play drum beats that required both arm and foot motion. Unfortunately, there is

a trade-off between the sense of agency and haptic support [TNLK22]. Shahu brought attention to the significance of maintaining user control [SWM22a]. Hence, based on the literature, it was crucial that we keep the user’s sense of agency intact when they engage in activities with Skillab in order to provide them with a more authentic experience [SWM22b, FKS22]. For Skillab, we adopted a wake-word activation method in our study, for users to have the upper hand and control over the system.

### 3.2.2 Skillab Prototype

We introduce the AR-based learning application “Skillab”, a Unity 3D-based program that includes the Vuforia Engine 10.8 as well as the Microsoft Mixed Reality Toolkit MRTK. It utilizes Microsoft HoloLens 2 as the digital eyewear for the prototype development.

#### Development

**AR-based System:** The AR environment displays step-by-step explanations including a textual summary, an illustration, and a recorded voice-over. An exemplary step with its description can be seen in Figure 3.7. Four sections make up the instruction panel. First, there is a progress bar at the top that displays how far you have progressed, followed by a text description on the left of the panel. On the right, there are graphics that illustrate the task at hand and the tool needed.

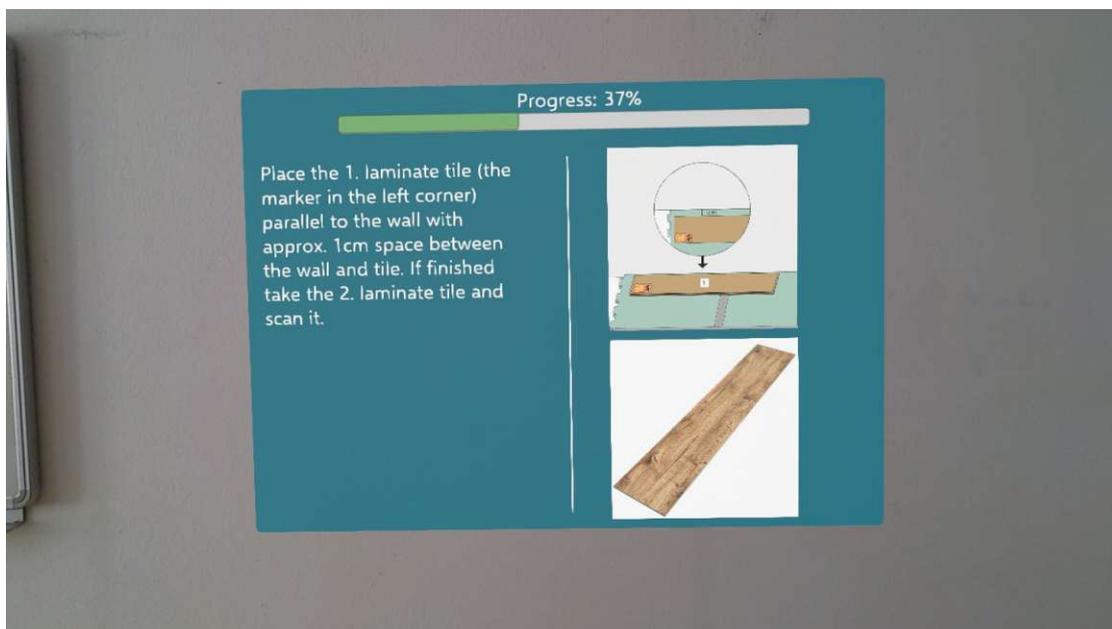


Figure 3.7: Instructions board with step-wise descriptions. Example: “Place the 1. laminate tile (with the marker in the left corner) parallel to the wall with approx. 1cm space between the wall and tile. If finished, take the 2. laminate tile and scan it.”

The primary functionality of the AR Guide, the detection of actual objects in the real environment, is made possible by the Vuforia Engine. The framework offers a marker-based detection called *VuMarks*. *VuMarks* are completely self-customizable markers that encode a variety of unique IDs into one marker design, comparable to QR-Codes. In our scenario, there are nine separate tools and items with individual *VuMarks*. Detecting a *VuMark* is rather easy; all that is required is for the user to hold the object and look directly at the marker through the HoloLens at a distance of approx. 20 to 30 cm. When the marker is successfully detected, an event is triggered, a sound indicates that the scanning was successful, and the appropriate task instructions are displayed.

The user can interact with the visualization and holograms via touch or speech in addition to seeing them through Microsoft's Mixed Reality Toolkit MRTK 2. Importantly, the *Interactable* component, which capsules the input and event handling, was employed<sup>10</sup>. An example of how it is employed is the voice command that participants used to start the guide. Following a brief explanation of the craft, users must speak "Vumarks" in order to start the application. It creates the impression that someone is observing them and understanding what they are doing. The *Manipulation handler*, which makes it possible to move, scale, or rotate a hologram, is another crucial component. In our case, this makes it possible to move the screen, which displays the instructions for the current work at hand, to the user's desired location for looking up the information<sup>11</sup>. The AR Environment incorporates both functional software and simulated functionality through a Wizard of Oz methodology, further described in Section 3.2.3.

**EMS:** The hardware for the EMS is an off-the-shelf, medically approved device we connected with Adafruit Feather 32u4 Bluefruit. Additionally, it has two channels, with channel 1 controlling the contraction of the biceps and channel 2 the contraction of the triceps. With the help of relays, it was feasible to turn the EMS channel on and off.

Using the Arduino software IDE for programming, we first set pins 6 and 9 to output. Following a 1000ms delay, we toggle both pins high and low, causing the arm to move upward when high (Figure 3.8a) and downward when low (Figure 3.8b). The muscle is actuated for a period of 1000ms, either lifting or dropping the arm up or down. Since this is a subjective parameter, it can be altered for each participant if they are unable to work at this pace during calibration. This time period was found to be the ideal time for the majority of people.

---

<sup>10</sup><https://docs.microsoft.com/en-us/windows/mixed-reality/mrtk-unity/mrtk2/features/ux-building-blocks/interactable?view=mrtkunity-2022-05> – Accessed July 2022

<sup>11</sup><https://docs.microsoft.com/en-us/windows/mixed-reality/mrtk-unity/mrtk2/features/ux-building-blocks/manipulation-handler?view=mrtkunity-2022-05> – Accessed July 2022

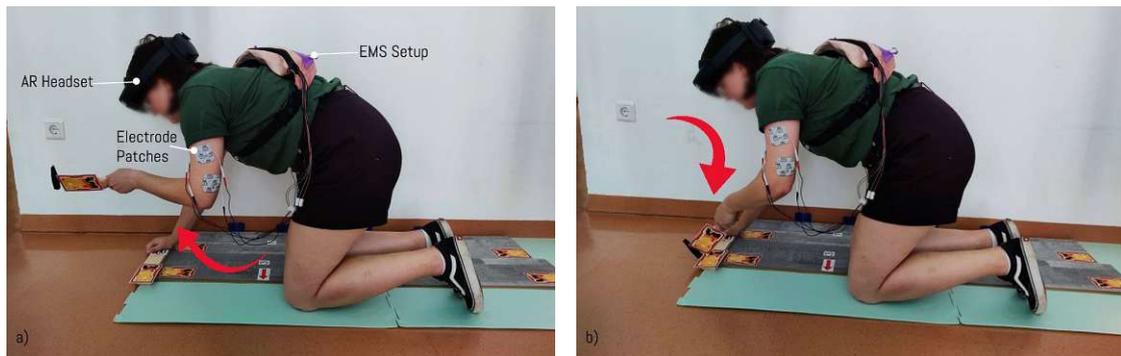
## Design

When the AR software is first launched, users enter the Instruction mode, where they see an instruction screen and hear a voiceover outlining the goal and subsequent steps. After uttering "VuMarks," the users enter the Demo mode, where the basic controls, such as moving and understanding the layout of the instruction panel (Figure 3.7), are described. Only 35% of the participants in our study (see Section 3.2.3) have experimented with augmented reality using digital eyeglasses like the Hololens, it was crucial to give the participants adequate time to become familiar with the controls and the technology. The demo mode instructs the user to scan the first required object after explaining how to scan things to fetch further details. After selecting the appropriate tool, a transition that the user cannot see occurs, and the main guide, which gives a detailed explanation of the process starts.

Since individuals complete tasks at a different pace, some people may need more time to review the task, whereas others may finish it faster by merely listening to the voiceovers. Therefore, automated skipping, for instance, depending on the time is impractical. Therefore, the Wizard of Oz technique is chosen for some parts. It offers the user a wide range of benefits, including the freedom to work unhindered throughout the creation of the craft and smooth transactions between processes. The participant is given instructions to grab the new object, scan and use it till the final step. The EMS tool is activated over a Wizard of Oz voice command if it is the final step, the step when the user must use a hammer to fix the tiles. This guarantees that users have control over when they wish to begin and stop allowing the system to actuate their muscles. Therefore, to start or stop EMS, the user must say "Start EMS" or "Stop EMS" respectively. In the final step of the guide, where the laminate tiles must be secured so they are not simply clicked but settled together, the EMS system aids the participants. As shown in Figure 3.8a and 3.8b, the fixing is done by pounding on a woodblock that is positioned at the short side of a laminate row. Two muscles, the biceps and triceps, must be alternately activated to replicate the arm movement of hammering. Consequently, two electrode patches are each placed on both muscles.

### 3.2.3 User Study

A portion of the study used the Wizard of Oz technique, due to the fact that every person requires a varied amount of time to finish a task. VuMarks were used to automate the scanning and consequently the identification of the tools and objects. Whereas the wizard pressed the key once the user had finished a step to display the next step using an obscured keyboard, it gave the impression that the system had fully understood the user's actions. By moving on to the next segment of the guide at the appropriate point, the Wizard assisted the participants. The Wizard of Oz technique creates the idea that the AR Environment is responsive in nature. Because of this, the participants get a good guided laminating experience, allowing them to completely concentrate on the craft. The process of laminating the floor was condensed into 10 basic steps with 4 tools and 8 pieces of material (Figure 3.9a). The primary goal was to gradually introduce the fundamental



(a) EMS supporting the arm up

(b) EMS supporting the arm down

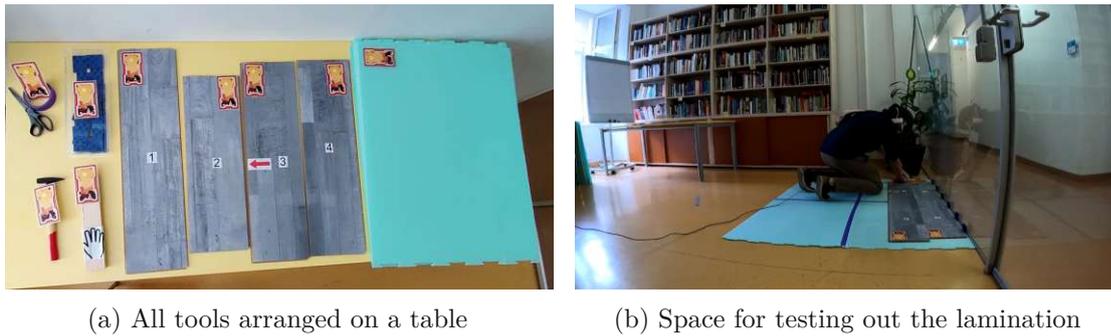
Figure 3.8: Participant receiving EMS assistance in the last tutorial stage.

procedures for this craft so that one can later effectively recreate the laminating process on their own. As seen in Figure 3.9b, the finished product of the guide is a small space where the participant learned how to prepare the floor, laminate, and fix four tiles.

#### Procedure

We divided the participants into two groups (between-subjects experimental design). In order to maintain an even distribution of sample sizes between the two groups, we used block randomization to divide the participants. One group received the AR guide with EMS, while another received paper instructions with identical textual descriptions and graphics in the same exact order. We made sure that the environment was set up uniformly for each participant, so we put all of the equipment and materials that came with the VuMarks on a table next to the area where they would laminate the floor. Everyone began at the same location, which was marked with a cross on the floor.

A brief oral introduction explaining the objectives, tasks, and safety precautions for muscle actuation was given to the participants. Next, they read and signed the consent form. For the participants in the Skillab group, the study started with the calibration of the EMS system, which comprised setting the electrodes in place and calibrating the pulse rate and pulse width. The last two parameters fell between 170-180us and 45-50hz respectively. The study proceeded with Hololens built-in eye calibration. Following this, the program was started and the participants were requested to follow the instructions. The moderator served as both the judge who evaluated the end result using the well-defined and structured rating schema (see Section 3.2.3) and the wizard who ensured that the guide continued at the proper time. After finishing the guide, the participants filled out the User Experience Questionnaire (UEQ) while the laminate was taken apart and placed back on the table. The participants re-did the lamination in an evaluation round without any instruction after a 10-minute break. The judge evaluated this round as well. Participants in both the Skillab vs. paper instructions groups completed the same surveys and underwent the same two-round process. Both rounds of the lamination



(a) All tools arranged on a table

(b) Space for testing out the lamination

Figure 3.9: User Study Setup.

process were evaluated and graded using a rating schema for both groups.

### Participants

We had a total of 20 participants (10 female, 10 male) ranging in age from 21 to 32 ( $M = 23.7$ ,  $SD = 2.3$ ) years. We found them through word-of-mouth and online forums via our university courses. 16 out of the 20 participants reported having no prior experience at all of laminating the floor, whereas 4 had some passive experience. These 4 people had merely observed as someone installed laminate flooring. In addition, 7 people have used digital eyewear to experience augmented reality. None of the 20 participants have ever engaged with EMS in any way.

### Measurements

Both quantitative and qualitative measurements were computed throughout the user study. Every floor lamination round was videotaped, and the interviews were audio-taped.

**Quantitative:** As a quantitative measurement, we recorded participants' completion time for each round (first round: *learning time*, second round: *evaluation time*). In order to compare and evaluate the final outcomes and the accuracy of the processes, we built a scoring rating schema. First, we simply determined whether or not each step had been applied correctly. If it wasn't correct, we took note of what went wrong, which advice was required, and how many pieces of advice, so that one error wouldn't affect the entire subsequent craft. There were a total of 9 steps that might be either correct or incorrect.

Next, we evaluated two components that were critical to the overall aesthetic and level of craftsmanship. First was the grading of the clamps; these were the spaces between the laminate tiles and the wall where a toeboard would eventually be mounted. Each participant in this stage was supposed to set a stack of clamps every 20 cm, at least 4 stacks of clamps. The clamps must then be turned correctly, that is, horizontally rather than vertically. For instance, if a participant adds at least four clamps in the proper direction, they receive a maximum score of 7 (Figure 3.10a). As shown in 3.10b, the



(a) Craft with a score of 19 out of 21 points.      (b) Craft with a score of 14 out of 21 points.

Figure 3.10: Sample craftwork from the study participants.

participant used fewer clamps and turned them in the wrong direction, hence the rating was low. The laminate tiles could simply be clicked together while laminating the floor, but hammering was required to secure them so that there was a seamless integration between them. Therefore, we gave it a maximum of 7 points if all of the tiles have been hammered and clicked into place (see Figure 3.10a), and only 3 points, for instance, if there are still tiny gaps. The rating of the craft's overall appearance came last; it considered the ratings of the clamps and the tiles as well as the alignment of all the tiles, including whether or not the ends are parallel. Again, the process was performed in both rounds (first round: *learning rating*, second round: *evaluation rating*).

**Qualitative:** The following topics were covered in our final semi-structured interviews: (1) General impressions (2) Learning-enhancing parameters (3) Experience with EMS (4) Pros and cons of the overall system covering the assistance or guidance they preferred; (5) Recommendations. We used the thematic analysis method to categorize and sort interview data. The core team consisted of four researchers (three females, and one male) with experience in HCI research. We used an online whiteboard tool (Miro) to facilitate discussion and categorization. Together, the four of us coded all of the interview transcripts. In accordance with various codes, we highlighted specific phrases using colors. We examined the codes we generated, searched for patterns among them, and developed themes. We got back to the data set and cross-verified our themes to make sure they accurately reflect the data and are valuable.

### 3.2.4 Results

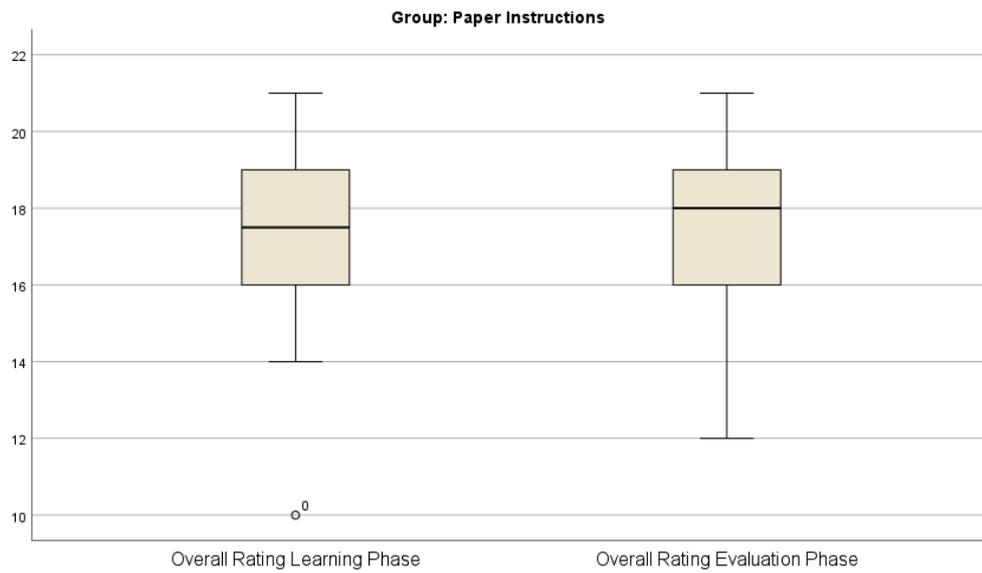
We present a detailed evaluation of the obtained results. Statistical comparisons were carried out using IBM SPSS Version 27, and the results are reported as statistically significant at  $p < .05$ . Based on the Shapiro-Wilk test, all data followed a normal distribution. We conducted an independent sample t-test for the two conditions, Skillab companion vs. paper instructions. We also conducted a pairwise t-test between the

training and the evaluation phase for both conditions. For the qualitative data, we categorized and sorted information using an affinity diagram. We sought to make sense of all the notes, observations, and discoveries we had recorded via the interviews by using themes to categorize the data and build throughlines.

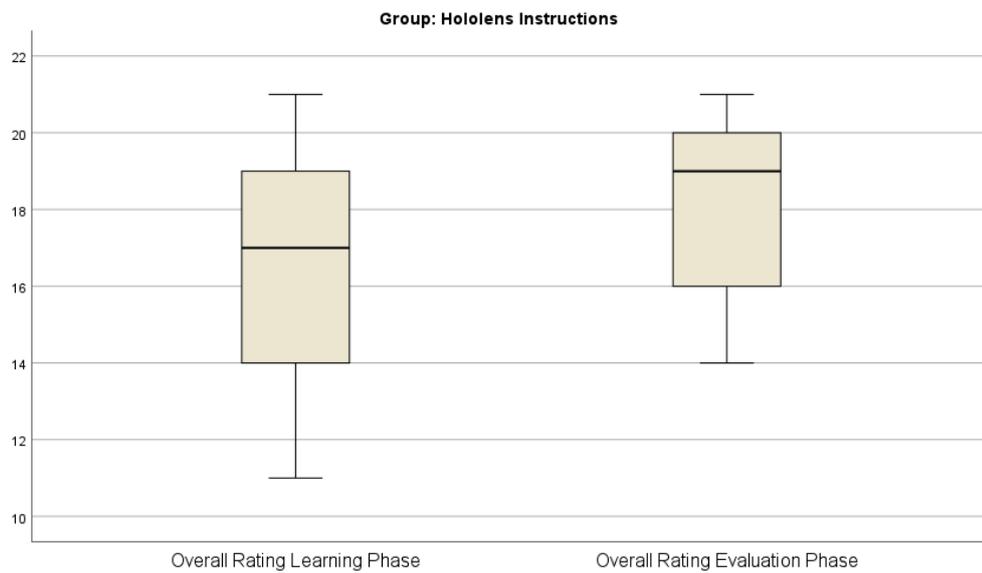
### Quantitative Data: Timing and Accuracy

In the Skillab tutorial, participants spent more time following every step of the instructions compared to the paper manual, where some parts were skipped or combined. *Participants could complete the evaluation round considerably more rapidly than the learning round in both conditions because we chose a task that was reasonably simple. For Skillab and paper instructions, total learning time vs. total evaluation time scores are strongly and positively correlated ( $r = 0.654$ ,  $p = 0.020$ ), ( $r = 0.583$ ,  $p = 0.039$ ) respectively [ This finding contributes to Chapter 7, subsection 7.3: Personalization and Adaptability.]* There was a significant mean difference between total learning time and total evaluation time scores for both Skillab ( $t = 17.533$ ,  $p < 0.001$ ) and paper instructions ( $t = 7.194$ ,  $p < 0.001$ ) tutorials. The task's repeatability following the learning phase was quicker, demonstrating reasonable levels of learning. A paired-sample t-test was conducted to compare the task performance score in the evaluation phase of Skillab and paper instruction conditions. There was a significant difference in the overall rating scores for the Skillab condition [ $t(9) = -2.805$ ,  $p = 0.021$ ]. There was not a significant difference in the overall rating scores for the paper instructions condition [ $t(9) = -.474$ ,  $p = 0.647$ ]. *For Skillab participants, the recreated craft work was of higher quality than the paper instructions (Figure 3.11a and 3.11b) [ This finding contributes to Chapter 7, subsection 7.3: Personalization and Adaptability.]* An independent-sample t-test was conducted to compare UEQ scores between the two conditions. There was a significant difference in the scores for both pragmatic items ( $t(18) =$ ,  $p = 0.034$ ) and hedonic items ( $t(18) =$ ,  $p = 0.030$ ) conditions. The pragmatic and hedonic item's values are higher for Skillab [( $M = 0.925$ ,  $SD = 0.457$ ), ( $M = 2.7$ ,  $SD = 0.346$ )] compared to paper instructions [( $M = 0.525$ ,  $SD = 0.463$ ), ( $M = 2.4$ ,  $SD = 0.316$ )] respectively. Overall ratings of the UEQ score were also significant ( $t(18) =$ ,  $p = 0.015$ ). The overall item's value was higher for Skillab ( $M = 1.812$ ,  $SD = 0.307$ ) than paper instructions ( $M = 1.462$ ,  $SD = 0.358$ ). *This demonstrated that the immersive multi-modal setting and playful learning style did have a substantial impact on the user experience. A two-sample t-test was performed to compare the total time taken in Skillab and paper instructions conditions [This finding contributes to Chapter 7, subsection 7.3: Cognitive and Emotional Support.]* There was a significant difference in the training phase between Skillab ( $M = 10:52$ ,  $SD = 1:30$ ) and paper instructions ( $M = 8:44$ ,  $SD = 2:25$ );  $t(18) = -2.364$ ,  $p = 0.015$ .

In a nutshell, Skillab requires more time investment from participants than paper instructions. The negative t-value and low p-value for the comparison of means suggest that this difference is unlikely to be due to chance. The positive correlations between learning and evaluation times in both conditions provide evidence of the consistency of the task across participants and the fact that participants who spent more time learning the



(a) Learning and Evaluation phase score for paper instructions



(b) Learning and Evaluation phase score for Skillab

Figure 3.11: Comparison of the overall task performance for Skillab and the Paper instructions.

task also tended to perform better in the evaluation phase. The paired t-test comparing overall rating scores in the evaluation phase between Skillab and paper instructions shows that participants who used Skillab had significantly higher ratings than those who used paper instructions. The negative t-value and low p-value suggest that this difference is also unlikely to be due to chance. The independent-sample t-test comparing UEQ scores between conditions shows significant differences in both pragmatic and hedonic items, as well as overall ratings. While these findings support Skillab companion's effectiveness, practical significance, and generalizability should be considered. The findings are based on a specific task and a specific group of participants, so one should be cautious when applying them to other contexts or populations.

### Qualitative Findings

Post learning and evaluation sessions, we conducted a brief interview with all the participants. We were interested in knowing what interaction helped them learn and what didn't. The following are the themes that emerged from the analysis:

**Convenience with Hololens:** Skillab enabled hands-free tool interaction. *Paper instructions required a lot of back-and-forth reading of the step-by-step instructions. One could position the panel on the Hololens however one chooses in the field of view or according to convenience [This finding contributes to Chapter 7, subsection 7.3: User Autonomy and Control.]* This improved the user experience overall by providing a more fluid and unhindered transition from one step to the next. One participant said *"I had the paper instructions, and then I left them on the table, so I always had to go back."* Another participant said *"With the Hololens I always had the instructions close by if I needed to look at them."*

**Interesting and exciting:** The novel way of working with AR technology to learn a new skill was interesting and exciting for our participants. The Vumark scanning and identification were described as gamification by many participants. An auditory response signaled that the scanning had been successful. One said *"It was more like playing games than actually doing work."* Another participant said *"Especially when laminating the floor, which is, I think, not so a fun task. Actually, it was just a lot more fun to do it with the Hololens."*

**Interactivity:** *Users had the impression that the system understood them and responded to them because they received confirmation after each step. The system provided ideas for error rectification when users picked up the wrong object and scanned it [This finding contributes to Chapter 7, subsection 7.3: Cognitive and Emotional Support.]* One participant mentioned *"I couldn't choose the wrong thing. So it prevents making some mistakes, and also you have this Learning by Doing and getting rewards feeling."* Some participants described having a companion who *"has your back"* so that they are not left to complete the activity alone. Some people claimed that receiving visual, audio, and tactile feedback at various stages aided in greater comprehension *[This finding contributes to Chapter 7, subsection 7.3: Collaborative and Relational Design.]*

**Paper is more flexible and self-paced:** Some reported when compared to the print-out guide, the tutorial's step-by-step breakdown through Skillab makes it easier and more beginner-friendly. This was not only presented as a pro argument but also as a con argument for those who favor skipping steps and doing them all at once. The printable instruction allows for customization by skipping or combining steps, however, the Skillab session does not. *Some people said they wanted complete control over the process [This finding contributes to Chapter 7, subsection 7.3: User Autonomy and Control.]* One participant said *"I think the step-by-step guide is nice because you can't skip a step that easily like when you have to place these little markers (clamps). For example, I almost forgot it in my first round."* On the other hand, one mentioned *"I think this was the main difference for me, so in the printout version, I always looked like two or three steps ahead, which I couldn't do with the Hololens."*

**EMS helpful in a foreign context:** *Participants highlighted the significance of using muscle actuation techniques when performing unfamiliar movements that are crucial to the job [This finding contributes to Chapter 7, subsection 7.3: Personalization and Adaptability.]* Some participants reported it helpful to use EMS as a support system for an entirely new interaction. They reported no compromise of the sense of agency. A participant reported *"If someone doesn't know how to make the movement, it really helps to learn it too because it gives cues, and you can then start yourself like amplifying these moves, but it gives you a very good hint of how to do things."*

**Assistance with power-demanding tasks:** *Some participants stated that when it comes to craftwork that needs higher power and heavier lifting, muscle actuation technology could be useful [This finding contributes to Chapter 7, subsection 7.3: Collaborative and Relational Design.]* It can, therefore, be employed as a method for supporting and strengthening muscles rather than just nudging the user in the right direction. One said *"I also think that this could greatly improve motor skills for elderly people, maybe because they can't just throw the hammer up and down. Maybe that's also for them."*

**Experiencing a sense of overload:** *Some participants initially found it difficult to understand how to accomplish some sub-tasks, but this changed as they became more accustomed to using Hololens [This finding contributes to Chapter 7, subsection 7.3: Cognitive and Emotional Support.]* One participant said *"I mean, at the beginning, it was a little bit overwhelming, so because everything was new and never worked with, one of those things. And at the start of the exercise, it was a little bit difficult for me to look at the charts here and listen to what it was saying and also do it."* Some people worry that if the technology fails, they won't be able to fix the problem and will have nothing left to complete the job. A participant showed concerns by saying *"Maybe if there are technical issues with the Hololens that maybe some people rely on the Hololens and do not know how to do it without it and they cannot work without it."*

### 3.2.5 Discussion

We have endeavored to understand the primary advantages and challenges of the "AR-based craft-work learning system" approach to skill development throughout this study. We discovered that learning occurred for the floor lamination activity using both Skillab application and paper instructions. In the following, we discuss our results in relation to our research questions.

#### Skillab companion vs. Traditional Paper Instructions

Using Skillab, participants took longer to finish the floor lamination task during the learning phase (*learning time*) compared to paper instructions. There could be multiple reasons for this observation. First, participants using Skillab had to frequently "scan" objects which took some time. Second, Skillab used the SBF framework, where participants were introduced to the tools, parts, and steps required for floor lamination. According to the Constructionism theory [Hin02], when learners construct and interact with physical objects, learning happens "felicitously." However, during the evaluation phase (*evaluation time*), both groups were able to repeat the task more quickly, demonstrating optimal levels of learning. According to the systematic rating score (*learning vs. evaluation rating*), the Skillab training showed a significant improvement, in contrast to the paper instructions learning. Despite no differences have been found when solely looking at the accuracy of the individual steps (a high number of steps have been carried out correctly in both conditions, i.e. *learning vs. evaluation correct*), this indicates that Skillab provided them with a deeper and more thorough level of learning to reproduce a high-quality craft work. AR-mediated scaffolds may be accountable for this. Every object and tool included both visual and audio instructions that described how the work was broken down and led users to the next step.

#### Advantages of Multi-modal AR Learning Environments

Despite the lack of statistically significant differences for some of the obtained parameters (in particular, *learning and evaluation time and correctness*), the learning process with Skillab was more controlled – participants using paper instructions used different strategies on how they approached the task. For example, some participants skipped some steps, and others combined steps and performed multiple at once. For floor lamination, this might not per se be a problem, but for learning more sensitive tasks like maintenance of Airplane engines, environments such as Skillab provide more fine-grained control over the process. This could help to reduce the effort of teachers in such areas as they would need less time monitoring their trainees while being able to focus on other aspects of training. Furthermore, Skillab offered participants an improved overall user experience than paper instructions, based on UEQ scores and follow-up interviews. Because AR enables hands-free interaction, our participants found it convenient to use in parallel with the floor lamination task. They were not required to alternate between reading and work completion. They also stated that the auditory feedback was quite helpful. Overall, they described the experience as enjoyable and fascinating; they felt as though they had

a partner who helped them through the entire lamination process, who understood them, and who responded in accordance with their actions and needs. The Skillab system's steadily immersive and interactive features appear to support and promote learning. This is in line with the previous research work [ZA03, RIP99].

The majority of the individuals responded favorably to EMS. None of our participants who used the EMS system mentioned feeling a loss of agency. It might be because we only turned the system on and off in response to voice commands from users. It is consistent with earlier research on the importance of preserving user control by Shahu and colleagues [SWM22a]. Participants believed that because they were already accustomed to hammering, the novelty of the system would be greater for an altogether unfamiliar motor movement. Despite the fact that Skillab provided a better overall experience, some participants emphasized that paper instructions are more adaptable. They are simpler to customize. Instead of following the process step-by-step, they might skip or combine some parts and study the entire instruction set first before even starting with the hands-on work. Due to their lack of experience with the Hololens setup, some participants first felt overwhelmed. However, they said that they quickly grew accustomed to it. Overall, Skillab companion acts as a good place to start when thinking about developing powerful immersive skill-building tools that promote craftsmanship. The companion experience, which aimed to integrate visual guidance (AR) with tactile, body-based feedback (EMS), successfully promoted a more immersive and physically grounded learning process

#### Limitations and Future Work

For this work, we had to deal with various limitations. First, concerning the technical setup. Skillab has limited accuracy and range as given by the used Hololens device and development frameworks. Additionally, calibration is needed for both the integrated EMS components and AR vision. Future research is needed to improve and partly automate such calibration steps. Also, the subsequent steps were triggered by a Wizard-of-Oz, while a real system would need to detect not only individual objects but also task boundaries and crafting quality to be able to switch between different "learning paths". Second, some limitations concern the user study. We did only compare Skillab to paper instructions. Previous research has already shown the advantage of AR over video tutorials in assembly tasks [LQB16]. The improvements in user engagement and perceived competence are likely the result of the combined use of AR and EMS, however, future research is needed to isolate the individual impact of each modality through controlled, comparative studies. Also, in future studies, we aim to improve Skillab according to the provided interview statements and perform an extensive cross-comparison between different learning methods, including videos, paper manuals, and human teachers. Further, our study included a well-defined sample of relatively homogeneous young participants, many with a technical background. It would be fascinating to see how various age groups respond to our prototype. Ultimately, it will be interesting to see how Skillab is perceived by DIY'ers of all ages and backgrounds.

### 3.2.6 Conclusion

In this case study, we introduce Skillab companion, an AR-based scaffolding system to support craftwork learning with immersive and multi-modal feedback. We implemented this concept by combining AR and EMS. The evaluation of the Skillab application revealed participants' interactions with AR scaffolds, challenges in learning, preferences, and overall user experience. The immersiveness and multi-modality of the AR-based system's feedback were its main benefits. Skillab users were encouraged to participate in each step of the process, which made it more understandable and simple to remember. As a result, the laminate work they created was of higher quality overall. Users appreciated the auditory input to advance to the next step and the auditory feedback regarding how well the step worked. The gamified learning aspects were enjoyable and engaging. These features of Skillab appear to support and promote learning and a positive user experience. The sense of agency was preserved by using the wake word to initiate and terminate EMS. The study's results indicate that skills acquisition platforms could provide a superior and captivating learning environment compared to traditional methods, particularly if combined with an immersive multimodal feedback system that enables task replication and learning while acknowledging the need for further research to validate these findings in broader contexts. The main challenge was that the prototype didn't provide them the freedom to modify specific steps in accordance with participant preferences. Steps should be adaptable for the user based on their preferences and past knowledge. Potentially, our work will inspire researchers to further delve into this avenue of applying immersive multi-modality feedback technologies for craftwork. We believe there are several ways that researchers can further expand on our work. Possible future investigations include exploring a) interactions with eye-tracking and visual gaze redirection, b) providing varying levels of customization, and c) improved object detection. Researchers can use the foundation provided by our work to investigate issues and expand on our system or findings in fresh ways.

## 3.3 Teleoperation Companion

This chapter is based on our following publication:

### Publication

Shahu, A., Kassem, K., Zehetgruber, L., Wintersberger, P., & Michahelles, F. (2023). Electrifying Obstacle Avoidance: Enhancing Teleoperation of Robots with EMS-Assisted Obstacle Avoidance. In *HHAI 2023: Augmenting Human Intellect* (pp. 224-233). IOS Press.

Robot teleoperation has applications in many domains, including search and rescue [CM03a], space exploration [PSK<sup>+</sup>20], mining [Hai01], tele-manufacturing [HYWTZ01], or surgery [Oka09]. The use of robot teleoperation allows for a combination of human and robotic traits to be utilized in a variety of settings, aiming to improve safety, efficiency,

and productivity. This is especially valuable to combine the advantages of both humans (creativity, problem-solving, fast adaptation, etc.) and robots (speed, precision, safety-critical environments, etc.). However, it is challenging to achieve the situational awareness required for collision avoidance [YDS04, LC93]. Multi-modal interfaces may help the human operator better perceive, understand, and predict the environment around the robot, leading to improved situational awareness and more informed decision-making. Vision can be used to provide the operator with a view of the surroundings, touch can help the operator accurately control the robot's movements and sound can provide important auditory cues about the environment. Haptic feedback can warn the operator of the presence of obstacles or other objects in the robot's path. The major focus of this study is haptic feedback, more specifically electrical muscle actuation.

Because haptic (and especially kinesthetic) feedback interfaces depend on mechanical actuators to exert force, they are often bulky and expensive [LB13]. EMS has the potential to provide feedback in a cost-effective and lightweight way, by applying small electrical stimuli leading to muscle contractions.

We investigated the potential of EMS-based companion for obstacle avoidance during robot teleoperation. To accomplish this, we developed a VR simulation of a robotic arm being controlled by a human user, where we compared bi-modal feedback with unimodal auditory and haptic feedback, as well as a baseline condition without support. The haptic feedback was provided through EMS being applied to the biceps and triceps of the user. We hypothesize that bi-modal feedback via companion improves collision avoidance and user experience, compared to relying solely on visuals.

#### 3.3.1 Related Work

When operating a robot remotely, operators' awareness of their surroundings often relies solely on the sensor and camera data, which may limit their understanding of the environment. The definition of situational awareness (SA) describes it as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" [End88]. Maintaining a high level of SA has been reported to be the most difficult part of many jobs [End21]. One of the most critical factors in decision-making by the operator squarely depends on how well the operator perceives the robot's environment [OZM<sup>+</sup>20]. Operators must not only be aware of their surroundings, but they must also process large amounts of information quickly and make decisions based on that information. Remote teleoperation may also require operators to switch between different views or modes of operation, which can add to the cognitive load. The cognitive workload that the operator has to analyze and interpret during teleoperation has a direct bearing on their performance [OZM<sup>+</sup>20]. The difficulty increases when the task also involves real-time obstacle avoidance [LC93]. Opiyo highlighted the importance of providing sufficient visual and force feedback to the operator to create a feeling of presence in the robot's environment, as well as using a good quality network, to improve the navigation efficiency and task accomplishment of mobile ground robots [OZM<sup>+</sup>20].

Prior research has shown that teleoperation interfaces heavily rely on visual information [CM03a]. Yet, it might be challenging to establish the SA required for teleoperation using solely visual cues [YDS04]. Che and colleagues designed a mechatronic device that allows bi-directional communication between a human and a robot follower [CCT<sup>+</sup>18]. The device has two parts: a haptic interface that gives users feedback from the robot and a command interface for remote control. The haptic feedback helped users understand the robot better, reduced mental effort, and improved performance on other tasks. The bi-directional communication strengthened the bond between the user and the robot follower. Kassem and the team conducted an assessment to determine the impact of various types of feedback, including audio, visual, haptic, and 3-way multi-modal feedback [KUWM22]. Objective and subjective measures were collected and analyzed, and the results showed that 3-way multi-modal feedback led to the best user experience and lowest task load. The use of multiple feedback channels did not increase cognitive load. The majority of teleoperation research focuses on improving the operator's sense of presence in a remote environment through various techniques, including the use of HMDs and force feedback [OZM<sup>+</sup>20]. According to Wildenbeest, when it comes to tasks that are familiar but imprecise, operators mainly depend on vision. In contrast, for tasks that are precise, unfamiliar, or not visually optimal, the significance of the haptic sensory channel becomes more critical [WAH<sup>+</sup>13]. Sagardia and team found that while completion time was mostly similar, the average collision force was substantially lower when using force feedback [SWH<sup>+</sup>12]. Pamungkas found that adding electro-tactile feedback from both force and distance sensors can help with avoiding obstacles in cluttered environments as well as with placing a peg in a hole when teleoperating a robotic arm [PW13]. The study appears to use only tactile feedback, and no published research on using EMS-based feedback for obstacle avoidance in robotic arm teleoperation was found at the time of writing the dissertation.

According to Rea's research, the cognitive burden of teleoperation is significant for both expert and non-expert operators, with most studies focusing on two primary issues: situation awareness and robot control [RS22]. User-centered solutions that process data and provide knowledge, rather than just information, could reduce workload and improve the ability of non-expert operators [RS22]. To improve teleoperation interfaces, Adamides created guidelines covering system design, communication, control, display, feedback, and user experience [ACK<sup>+</sup>15]. These guidelines aim to enhance the usability and effectiveness of teleoperation interfaces, especially in situations where the operator controls the robot from a distance.

Drawing upon insights from prior research, the present study was designed to investigate the effects of obstacle avoidance on the objective and subjective quality of remote robot control, through the utilization of distinct feedback modalities - namely, auditory and haptic feedback. We framed our research questions as follows:

- **RQ 1:** What is the objective effect of using audio and haptic feedback on collision avoidance?

- **RQ 2:** How do the different modalities influence the subjective hedonic and pragmatic qualities of user experience?
- **RQ 3:** In what way do the different modalities affect task workload?

#### 3.3.2 Method

We developed a user study in which participants operated a robot in VR. A within-group study design was employed. To address the potential bias caused by repeated practice, a balanced Latin square design of size 4 was implemented to randomize the order in which participants experienced the four experimental conditions. The balanced Latin squares helped to control for the order effect and allowed for a more accurate evaluation of the impact of each feedback modality on task performance. Participants are placed in a tutorial environment to familiarize themselves with the task and controls before the measurements begin, and they are encouraged to practice until the conveyor belt reaches maximum speed in the tutorial environment.

#### Task Description

The study required participants to use VR to control a stationary robotic arm to perform a task at a simulated remote location. The location had a conveyor belt, and the robotic arm was positioned beside it. Boxes moved along the conveyor belt from right to left, from the perspective of the robot when the end effector was pointing towards the belt (shown in Figure 3.12a). The participants had a third-person view of the robotic arm, which included a view of the boxes moving and a partial view of the robotic arm being controlled. The participants had to control the robotic arm to scan a simulated object on the top face of the boxes when they came within the reach of the end effector (Depicted in Figure 3.12b).

The movements of the robotic arm were controlled by the position and rotation of the VR controller, which were mapped to the position and rotation of the end effector. As the boxes moving along the conveyor belt were of different heights, the end effector had to move up and down to avoid colliding with the boxes. Participants had to press the designated button on the VR handheld controller to scan the object when the end effector was within a volume above the top face of the box. If the scan was not performed within this volume, it was considered an error.

Each box required a secondary scanning action further down the conveyor belt. The secondary scanning action was done through a different stationary downward-facing scanner situated above the conveyor belt (shown in Figure 3.12c). Participants had to press a different button on the controller when the box was immediately below the scanner (depicted in Figure 3.12d). Performing the secondary scan before or after the box was immediately below the stationary scanner was considered an error. The task difficulty increased over time, as the speed of the conveyor belt ramped up while decreasing the interval at which new boxes came onto the belt. The robot operator had to simultaneously

give sufficient attention to both the primary and secondary scanning actions to avoid errors while the boxes were in motion.

### Apparatus

For interacting with the robot in VR, we used a commercial HMD equipped with stereo speakers and dual wireless hand-held controllers<sup>12</sup>. For the purpose of our study, we relied only on one controller for controlling the vertical position of the robot end effector. We built the virtual environment inside the Unity 3D engine<sup>13</sup>. Inside the virtual environment, we used a common industrial collaborative robot<sup>14</sup>. The VR application communicates with the EMS circuit via an Adafruit Feather 32u4 Bluefruit LE microcontroller, which controls two relays to open or close the circuit for the desired muscle stimulation. A standard two-channel EMS device provides the electrical current, and the control circuit is carried in a small bag by participants and connected to the PC with a USB cable.

### Feedback and Conditions

The study's participants were tasked with controlling a stationary robotic arm in VR to complete a task at a simulated remote location. As boxes moved along a conveyor belt, participants had to move the arm up or down to avoid collision with the boxes or low ceiling. The participants received feedback through three modalities: visual (through the VR headset), auditory (through the integrated speakers on the headset), and haptic (through the nudges of the EMS system). To avoid any cascade effect, the collision with boxes was programmed to allow the robotic arm to pass through them, and the affected boxes' color turned red to indicate a collision.

The task is presented in four different conditions:

1. **Baseline:** No feedback was given, and participants had to rely solely on visual perception.
2. **Auditory feedback:** Participants received feedback to move their arm up or down through a voice saying “up” or “down,” respectively.
3. **Haptic feedback:** Participants received a nudge through the two pairs of electrodes on their biceps and triceps, stimulating the biceps to nudge the participant's forearm upwards and the triceps to nudge it downwards.
4. **Multi-modal:** Participants received both auditory and haptic feedback simultaneously.

During the task, participants had to simultaneously attend to both scanning actions while avoiding errors caused by the boxes' motion.

<sup>12</sup>Meta Quest 2 <https://www.meta.com/quest/products/quest-2/> – Accessed July 2022

<sup>13</sup><https://unity.com/> – Accessed July 2022

<sup>14</sup>UR5e <https://www.universal-robots.com/products/ur5-robot/> – Accessed July 2022

## Participants

The study recruited 9 right-handed participants (mean age 23.9, SD 1.6) who did not have specific medical conditions or metal implants and were not pregnant or using an insulin pump, with the additional requirement of not wearing glasses that were incompatible with the VR headset. All participants signed a consent form indicating their willingness to take part in the study and to allow their data to be collected and analyzed. They received compensation in the form of a voucher. To calibrate EMS, the stimulation intensity was slowly increased, and participants were asked to indicate when they felt a slight but noticeable movement in the direction required and the resulting intensity was then maintained throughout the study, with adjustments made to the electrode placement or intensity if the stimulation became uncomfortable. The specific voltage and current levels used for each channel were independently adjusted to achieve the desired level of stimulation for each muscle group, which depended on the individual's muscle size and sensitivity.

## Measurements

The primary performance metrics of interest are the *collision count* and *collision time*, while the *error rate* (the ratio of incorrectly to correctly scanned boxes) is also measured to ensure that collision avoidance does not have a significant negative impact on task execution performance. After completing a task under specific conditions, the participants filled out a set of condition-specific questionnaires, which included the User Experience Questionnaire [SHT17a] and NASA TLX [HS88].

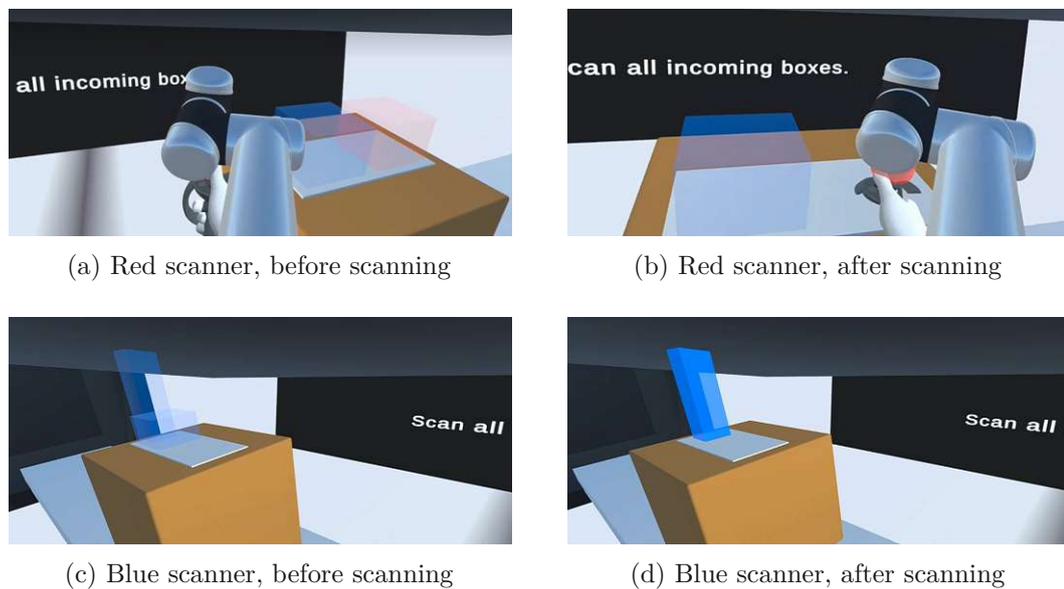


Figure 3.12: Views of the two subtasks, right before and after scanning.

### 3.3.3 Results

The data was evaluated using JASP 0.16.3-Debug [JAS22].

**Performance Metrics** : The trends indicate that using EMS and a combination of auditory and haptic feedback leads to fewer *collision count* and shorter *collision time*. The Friedman test shows no significant differences across the four conditions for any of *collision count* ( $\chi^2(3) = 0.771, p = 0.856, N = 9$ ), *collision time* ( $\chi^2(3) = 1.042, p = .791, N = 9$ ) and *error rate* ( $\chi^2(3) = 4.724, p = .193, N = 9$ ). This could be due to the limited number of participants involved in the study or the potential influence of a learning effect.

**User Experience Questionnaire** :

- **Pragmatic Quality:** A repeated measures ANOVA shows a significant difference in pragmatic quality ( $F(3, 24) = 4.104, p = .017$ ) between at least two conditions (Illustrated in Figure 3.13a). Bonferroni-corrected pairwise comparisons revealed a significant difference only between the baseline and EMS condition (mean =  $-1.778, p = .018$ ).
- **Hedonic Quality:** A repeated measures ANOVA shows a significant difference in hedonic quality ( $F(3, 24) = 33.488, p < .001$ ) between at least two conditions. Post-hoc tests with a Bonferroni-correction revealed that the hedonic quality was significantly worse in the baseline than in any other condition (Baseline-Auditory): mean =  $-1.000, p = .014$ ; (Baseline-EMS): mean =  $-2.556, p < .001$ ; (Baseline-bi-modal auditory-haptic): mean =  $-2.361, p < .001$ ). Furthermore, the hedonic quality of the audio-only condition was significantly worse than either condition involving EMS (Auditory - EMS): mean =  $-1.556, p < .001$ ; (Auditory - bi-modal auditory-haptic): mean =  $-1.361, p < .001$ ). There was no significant difference between the EMS-only and the combined condition (illustrated in Figure 3.13b).

**Task Load** : A tendency of feedback to lower the task load can be seen in Figure 3.13c. The repeated measures ANOVA shows no significant difference across the four conditions ( $F(3, 24) = .777, p = .518$ ).

### 3.3.4 Discussion

The study found that using EMS feedback combined with auditory feedback can potentially result in fewer collisions and shorter collision time (RQ1). The use of EMS feedback is advantageous due to its quick and intuitive nature, allowing users to react promptly to changes in their environment. The combination of auditory and haptic feedback can also provide multiple sources of information, enabling users to better understand their surroundings. However, further research with larger sample sizes is necessary to

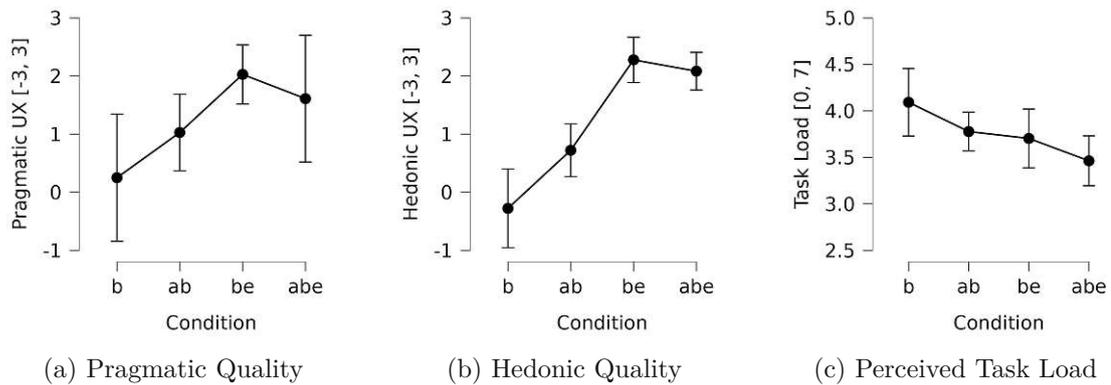


Figure 3.13: Plots of the means and 95% confidence intervals of the two UEQ-S scales and of the Task load - [b: Baseline, ab: Auditory, be: EMS, abe: Bi-modal auditory-haptic.]

establish more definitive results. In terms of user experience (RQ2), the study revealed that haptic feedback was preferred over other feedback modalities, indicating that it received the highest rating in both pragmatic and hedonic quality scales. The immediacy of EMS feedback was also found to be more favorable than processing visual or auditory information. Additionally, all three cuing conditions were rated to have a lower task load than the baseline, suggesting that any additional feedback can reduce the perceived task load of the remote operator (RQ3). However, some participants expressed that the combination of EMS and auditory feedback was overwhelming, raising concerns about whether the bi-modal feedback could be better designed to prevent sensorial overload. Although the sample size was small, the study offers a valuable starting point for further research and provides insightful information. Notably, the study highlights the importance of learning in the task, as participants demonstrated improvements in collision avoidance and error rates over time, refining their overall strategies to facilitate better collision avoidance. However, the measures taken to mitigate the effects of learning were inadequate. Overall, the study suggests that muscle actuation feedback, such as EMS, can be a promising approach to enhancing teleoperation performance by providing additional sensory information to the operator. Nonetheless, more research is needed to fully understand the potential benefits and limitations of this approach

**Limitations and Future work** To better understand the usefulness of EMS feedback in robot teleoperation for obstacle avoidance, a user study with a larger sample size is needed to uncover any significant differences. To improve the quality of the EMS feedback, a simple spring-damper model could be implemented to adjust the stimulation intensity based on the proximity to obstacles, which may increase both performance and user comfort [JSH11]. The study was affected by a learning effect because the task was not complex enough. To reduce this effect, the authors propose modifying the task setup in future experiments. The study did not explore other potential methods of evaluating situational awareness, which may be more effective. Additionally, it would be intriguing to compare EMS with electro-tactile feedback.

### 3.3.5 Conclusion

Using teleoperation to control robots can be challenging due to the lack of physical presence and direct interaction. To address this, our research proposed using EMS as a haptic feedback source in combination with auditory and haptic feedback to improve obstacle avoidance. The study showed that using EMS feedback led to fewer collisions and shorter collision times, as well as reduced task load compared to no feedback. Haptic feedback was rated the highest in both pragmatic and hedonic quality scales, followed by bi-modal auditory-haptic feedback. The use of muscle actuation technology was reported to offer a positive user experience for obstacle avoidance. Although the sample size was small, the study serves as a foundation for future research, and increasing the number of participants may produce more positive results. Muscle actuation feedback may be used to communicate information about the robot's applied force or torque, as well as the shape or texture of the remote environment. Overall, muscle actuation feedback shows promise in improving teleoperation performance by supplementing operators with additional sensory information.

## 3.4 Acceptance of EMS

This chapter is based on our following publication:

### My Publications

1. Shahu, A., Wintersberger, P., & Michahelles, F. (2022, April). Would users accept electric muscle stimulation controlling their body? Insights from a scenario-based investigation. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts* (pp. 1-7).
2. Shahu, A., Wintersberger, P., & Michahelles, F. (2022, March). Scenario-based investigation of acceptance of electric muscle stimulation. In *Proceedings of the Augmented Humans International Conference 2022* (pp. 184-194).

In body-based user interfaces, EMS has evolved as an output paradigm in the last decade. The fundamental concept is to stimulate users' muscles with electric pulses from a device attached to their bodies, allowing them to move their limbs. While EMS has been extensively studied in medicine, genetics, biomechanics, and psychology, it is only recently that the human-computer interaction (HCI) community has taken an interest in the technology. Motor learning [TMR11], force feedback [LYIB18], transmitting object affordances [LJB15b], pedestrian walking/navigation aids [PDS<sup>+</sup>15], and aided drawing [LYGB16] have all been presented as uses for EMS prototypes.

EMS as technology takes a step further by allowing machine output to be fed directly into human motor control due to its capacity to generate a muscle contraction. This is a one-of-a-kind trait that broadens the scope of "person in the loop" systems. Lopes et al. (2015), for example, used EMS to protect users from burning their hands by merely

bending the wrist away from a cup of hot water [LJB15b]. Another example is the work by Schneegass and Rzayev (2016), which wrenched users' arms to make them glance at their watches in order to remind them of approaching meetings [SR16]. Automation may "skip" human information processing stages (such as the perceptual level) and go straight to the action stage by using such interfaces.

On the other hand, this trait might be a significant roadblock to the widespread adoption of EMS technology in HCI. EMS interfaces may restrict users' sense of agency (i.e., their perception of being in charge) by bypassing the cognitive system, presenting ethical and even philosophical difficulties. Controllability is a central problem in various fields, including human-AI and human-automation interaction. For example, it is a substantial impediment to societal acceptance of autonomous driving systems [FWLR19], [RJAF17]. As a result, while considering EMS-based interfaces, a key question to consider is: *Would users accept a technology that directly interacts with their muscles?*

Existing work has typically been evaluated by showing its benefits on users' performance (e.g., [EHS<sup>+</sup>17], [TMR11]), demonstrating user understanding of stimulated movements (e.g., [PSA13], [HRP20]), showing that users can mimic movements generated by EMS (e.g., [HDW<sup>+</sup>17], [LB20]), or by delighting users in novel experiences [LB17a], [LYIB18]. Some of these studies have briefly reported subjective comments from users, which indicate doubts, for example, "*I felt like my forearm was pushed by someone.*", "*I felt like when I got a cramp in my arm.*" or "*I felt like my body was hacked.*" [TMR11]. To our knowledge, a systematic assessment of EMS technology from the standpoint of user acceptance is still missing.

We aimed to contribute to these concerns with this article by evaluating the user acceptance of various scenarios depicting prospective EMS use cases. We developed various dimensions from a literature review that may be used to define how this technology is utilized, and we used these dimensions to create four scenarios based on current prototypes. We then evaluated these scenarios in a two-tier study approach: First, we conducted an online survey with N=113 participants, who received written descriptions and representative images of these scenarios and completed the technology acceptance model with trust integration [VD00, VMDD03, BCF12]. The statistical analyses of the results revealed potential concerns of future EMS usage. However, since the survey could not include real experiences with EMS technology, we validated our results in a subsequent in-depth interview study. 5 Participants experienced an EMS system in our lab before we discussed emerging possibilities and potential issues considering the derived scenarios. With the results of both studies, we want to contribute to this line of research by identifying potential pitfalls and opportunities for the design of novel EMS systems and prototypes in HCI.

#### 3.4.1 Related Work

In this part, we define user acceptance, provide a brief overview of EMS systems presented in the HCI sector, and create dimensions to characterize these systems in relation to our

study objectives.

### User Acceptance as a Precursor to Technology Use

One of the most critical factors in determining whether technology succeeds or fails is user acceptance. The *Technology Acceptance Model* (TAM) was suggested by Davis (1993), and is based on the Psychological Attitude Paradigm [FA77, Dav93], which links users' values, attitudes, and (possible) behaviors. The perceived usefulness (PU) and perceived ease of use (PeOU) of an external stimulus or design feature influence the general attitude toward utilizing a device (ATT, emotional reaction) in the TAM, which adds to system usage or disuse (Intent, i.e., the behavioral response). Over time, the TAM has been updated, resulting in TAM 2 [VD00] and TAM 3 [VMDD03]. We used a TAM extension given by Belanche et al. (2012) since trust in automation is an essential additional aspect [BCF12]. They discovered that trust is tightly connected to both attitude and purpose of usage, making it a third belief "*able to explain the mechanism.*"

### Electric Muscle Stimulation

**Theory:** By inducing electrical current into the muscles, EMS replicates the body's natural electrical impulses, which can result in muscle contraction and, as a result, bodily motions. To provide such electrical impulses, typical EMS systems employ a pair of electrodes (a cathode and an anode), according to [KIMR18]. When current travels from cathode to anode, it flows via nerves and motor neurons, increasing the internal voltage of the neurons. When a particular threshold is exceeded, the motor neurons "fire," causing the muscles connected with these neurons to contract [KIMR18], [PDR16]. The amount of force required to trigger a muscle differs between body regions and users, necessitating a calibration procedure to assure pain-free operation [KAH18].

**EMS in HCI:** EMS opens up many possibilities for new interaction scenarios. It can be utilized to transmit object affordances [LJB15b], trigger direct user movements [LB17b] [LIM<sup>+</sup>15], or offer haptic feedback [LB20] by varying stimulus parameters (i.e., amplitudes, pulse widths, frequencies). "PossessedHand" [TMR11], which controlled a user's fingers, was one of the earliest demos in the realm of HCI. Users' arms were triggered by Affordance++ [LJB15b] to notify them about how they should communicate with an object. Lopes et al. (2017) have proposed to use EMS in virtual reality environments [LYC<sup>+</sup>17b]. To simulate the sensation of hitting or being hit in VR boxing, Impacto employed a combination of tactile feedback (a solenoid tapping the skin) and EMS [LIB15].

Jain et al. (2017) utilized EMS on the wrist muscles to recreate the experience of a ball striking a racket in an augmented-reality tennis game [JSB17]. Kasahara et al. (2019) have proposed that technology be used to improve human reaction times [KNL19b]. They demonstrated that things could be grasped faster than usual with suitable signal stimulation time. Pose-IO offered both input and output based on proprioception sense

using EMS [LIM<sup>+</sup>15]. Users supplied data by bending their wrists in an input motion, which a 3-axis accelerometer detected. When a user's wrist was positioned in an output gesture, which Pose-IO activated via EMS [LIM<sup>+</sup>15], Pose-IO output was initiated.

EMS was also utilized for training and support. Ebisu et al. (2018), for example, controlled users' motions to teach them how to play percussion instruments by simulating both their arms and legs [EHO18]. Students could take up the rhythm even though no experienced percussionists were involved in the process. Students may learn both the beat of one hand and the rhythm of both hands simultaneously. It was also feasible to play drum rhythms that needed both arm and foot movement. Nith et al. (2021) proposed dextrEMS, a haptic device based on EMS with mechanical brakes at each finger joint [NTL<sup>+</sup>21]. The basic concept of dextrEMS is that while the EMS actuates the fingers, the mechanical brake ensures that they are stopped in a precise location. They demonstrated it in a variety of situations, including a piano lesson, a guitar lesson, and a VR game.

The use of EMS for pedestrian navigation has also been explored. "FootStriker" recognized heel striking while running and corrected it in real-time to mid-/forefoot running by administering EMS to one of the calf muscles [HDW<sup>+</sup>17]. Others have utilized EMS to make users smile [YCFK<sup>+</sup>17], stimulated face muscles to create food textures when eating [NO16], and even stimulation of abdominal and laryngeal muscles has been suggested as a viable approach to aid vocalists in a vibrato [FFN<sup>+</sup>17]. Finally, by coupling the actuation of the human body with the activation of senses, several researchers employed EMS to examine embodied emotional feedback [HPS<sup>+</sup>17].

Users' perceptions have been tested in some of the experiments mentioned above, with conflicting findings in terms of user approval. Participants in the Pohl et al. (2018) research, for example, despised the increasing temporal rhythms of EMS as the signal amplitude grew [PHK18]. Participants in the [PHK18] and [Poh93] studies have also responded to EMS, resulting in a "a weird feeling" when they "can't control their muscles." Prospective users' sense of control appears to be crucial. Consequently, we have reason to doubt that potential users will blindly accept and use EMS systems in their daily lives.

**EMS Taxonomy - Not all systems are equal:** A deeper look at the mentioned EMS prototypes reveals that they may be categorized differently. We believe that classifying data in this way will make it easier to compare and generalize the outcomes of a particular prototype. We came up with the following list based on the literature:

**Controllability:** This dimension refers to a user's capacity to control a situation (sometimes referred to as "sense of agency"). When employing EMS in VR [LYC<sup>+</sup>17b], for example, the system's response matches the user's behavior in the simulated environment (i.e., *high controllability*). In contrast, an EMS system that makes users do things they do not want to do (like smile [NO16] or alter walking direction [PDS<sup>+</sup>15]) implies *low controllability*.

**Intrusiveness:** The EMS system is involuntary in nature since it bypasses the user’s conscious control. This category denotes how intriguing an EMS interface may appear. *High intrusiveness*, for example, is apparent when a system exerts excessive control over your bodily parts (such as [TMR11]). Other prototypes, such as [PSA13], may intervene in the user’s life in a brief and sporadic way as they are more immersive in nature.

**Longevity:** An EMS interface may continually stimulate muscles (for example, [LYGB16]), but other systems (for example, [LJB15b], which prevents users from grabbing a hot mug) only trigger users in specific scenarios and for a limited length of time.

**Safety-criticality:** Further, the coffee mug prototype is an example of EMS being used to prevent a safety-critical situation [LJB15b]. Also, pedestrian navigation [PDS<sup>+</sup>15] operates in a potentially safety-critical environment. Other environments (such as VR feedback) where EMS is used are less critical.

**Open vs. closed loop:** Some prototypes have combined muscle reading and muscle writing (electromyography with EMS) [HRP20] or other input modalities (like VR-controller). Such systems allow users to manipulate their limbs to provide input to the system. Although this is not a property of EMS systems per se, consumers might likely be unaware of the technological difference.

### 3.4.2 Method and Research Questions

We derived four EMS-based interaction scenarios based on our literature study that varied along the aspects outlined above (see Table 3.2). Although there are many more EMS scenarios, particularly those connected to rehabilitation ([KS20], [SGMS17]), we focused on possible daily uses for a broad audience rather than specialist ones:

**Motor Learning:** EMS could be a promising technology to fasten the learning progress for motoric tasks (see [TMR11], [EHO18]). We used the example of guitar playing, where EMS could support a user during a motor skill-building activity (i.e., automatically following the guitar tabs).

**Virtual Reality:** In this scenario, EMS supported immersion in VR environments by providing situation-specific haptic feedback (see [LYC<sup>+</sup>17b] [LYIB18]). For example, when a user picked a chair in VR, s/he could feel the resistance of holding the object.

**Media Player:** EMS may support classical interactions such as substituting screen controls. We used the example of a Media Player (see [LIM<sup>+</sup>15]), where the current progress of the video is reflected on the user’s body, while at the same time the user can perform actions (such as rewind/forward the video) using muscle reading. The hand

position is mapped to the video's timeline - a straight wrist marking the beginning of the video, a fully flexed wrist marking the ending.

**Road Safety:** As EMS was already used for pedestrian navigation (see [PDS<sup>+</sup>15]), we hypothesized how this could be extended to increase pedestrian safety. We described a scenario where a user would be held back by the system in critical situations, for example, when stepping onto the street when a fast car is approaching.

Those scenarios illustrate various manifestations of the EMS categories we proposed (see Table 3.2). EMS signals, for example, regulate user motions for a more extended amount of time in the Motor Learning and Media Player scenarios than they do in the VR and Road Safety scenarios, which operate on an event basis. Similarly, controllability is lower in the Motor Learning and Road Safety situations than in the other two. The only safety-critical setting is the Road Safety scenario. Media Player scenarios feature both types of interaction directionality (muscle reading and muscle writing).

Table 3.2: This table shows the different dimensions along which we categorized EMS-based systems. This list was elaborated by reviewing recent literature on the topic.

Scenario	Controllability	Intrusiveness	Longevity	Safety-criticality	Open vs. closed loop
Motor Learning	Low	High	High	Low	Open
Virtual Objects	High	Low	Low	Low	Open
Media player	High	High	High	Low	Closed
Road safety	Low	High	Low	High	Open

We then created short descriptions and images for each of the 4 scenarios (see Figure 3.14), which have been used in both the online survey and the interview study:

**Motor Learning:** Imagine you want to learn a new musical instrument, let us say: a guitar. Learning guitar from scratch takes several years until you can control your fingers properly. However, a much faster way to learn motor skills is to put an EMS system onto your hand, which then stimulates your finger muscles using continuous electric signals during the training session. So, you can even play your first song already in the first training session. Potentially learning new tasks will become much easier using EMS systems. You would constantly feel the EMS operating your muscles while playing the instrument in this scenario. Imagine yourself learning a new instrument using this EMS technology.

**VR:** Current virtual reality environments lack the haptic dimension. When you lift an object in a virtual environment, it feels unreal and disengaging as no object weight is experienced. Imagine the next step towards realism and immersion, and an EMS system can support the haptic sense to convey the physicality of the virtual world. If you would try to push an object away in a virtual environment, at that instant EMS system would create a counterforce that would pull your arm backward. This can significantly enhance the experience and can make it more fun. In this scenario, you would feel the EMS in

certain limited situations, such as grabbing or colliding with an object. Imagine yourself playing a game in VR using this EMS technology.

**Media Player:** Imagine interacting with a device through the pose of your body rather than clicking on a button or talking to your phone. EMS system would understand your gestural command and perform the needed action. For instance, you can control video playback using your wrist. EMS system can tightly couple the position of your wrist with the position of the video play head. You can set the position of the play head by posing your wrist. In this scenario, you would constantly feel the EMS operating your muscles while interacting.

**Road Safety:** Traffic safety is an important issue, and the number of pedestrians involved in accidents has increased over the last years. Often, pedestrians are overrun as they do not pay sufficient attention to the road environment. EMS systems may improve pedestrian safety, as preemptive feedback can speed up human reaction time. Imagine yourself wearing an EMS device that senses nearby vehicles and preemptively stops you from stepping on the street in critical situations (i.e., a fast car approaching) to ensure your safety by sending an electrical signal. You might feel a buzz and, for a short moment, not be in control of your body. However, the system prevents you from stepping on the road and being hit by a car. You would feel the EMS operating your muscles only in short, safety-critical situations in this scenario.

By statistical evaluation of the TAM ratings and affinity mapping of the interview statements, we aimed at answering the following research question: **Which EMS interaction scenarios are accepted by users and why, and can the findings be related to system properties/dimensions?** We briefly informed the participants about EMS technology before we began the study. We explained to them that it's mostly utilized as a rehabilitation and prevention tool for individuals who are partially or completely immobilized. It's an off-the-shelf device that's completely safe to use. It allows the user to modify and adjust the signal's intensity to create the desired sensory experiences.

### 3.4.3 Online Survey

The four scenarios (descriptions and images) were presented in randomized order. We emphasized that each scenario would work technically sophisticated and error-free. Consequently, they were asked to score their acceptance based on their personal feelings about these situations rather than on their doubts about whether one or the other could be supported by technology. They completed the survey questions rating their user acceptance after each scenario. At the end of the survey, participants completed additional demographics and technology affinity questions.

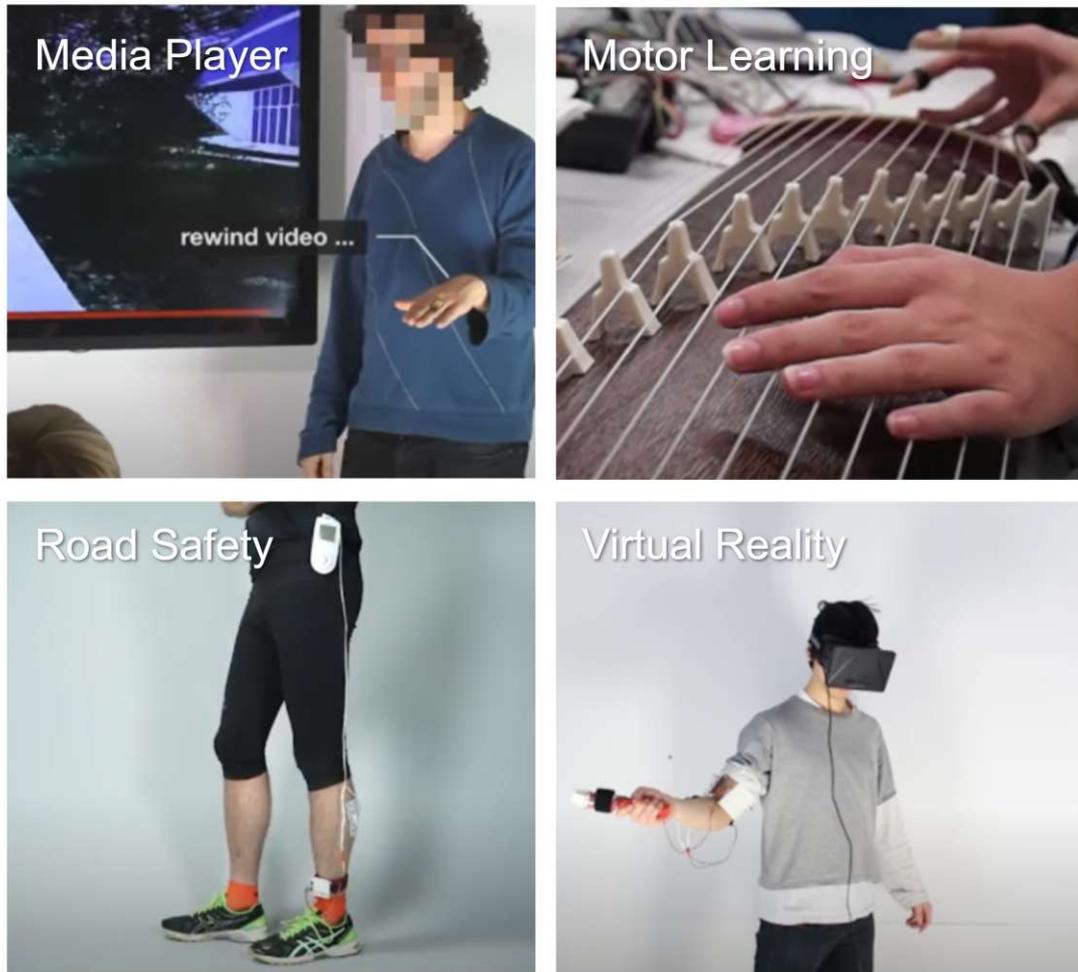


Figure 3.14: Images were used to give study participants an impression of the scenarios.

#### Participants and Procedure

The study was set up and conducted in English. We relied on a random sampling technique for the selection of the participants. We distributed the survey on university mailing lists and social media. After completing the consent form, participants were presented with a short comic-book-like sketch describing EMS technology and how it works. In total, 113 respondents (77 males, 31 females, 3 diverse, and 3 preferred not to provide details) participated in the survey. The mean age of the participants was 28.69 (SD = 7.31) years. 77.2 % of the participants had no prior experience with EMS, with the rest having only done so in the context of medical applications or pain treatment. The duration of the survey was approximately 30 minutes per participant.

## Measurements

To assess user acceptance, participants completed the TAM with trust extension based on Belanche et al. (2012) [BCF12]. According to Cronbach's  $\alpha$ , the scale reliability is acceptable for all sub-scales (around .7). The model includes the perceived usefulness (PU), perceived ease of use (PEoU), attitude towards using the system (ATT), safety and trust in automation (trust), as well as intention to use the system (Int). Consequently, we built scale values of all TAM dimensions for evaluation (see Table 3.3). Further, we included the affinity for technology interaction questionnaire ([AWF17], [FAW19]) to find out if acceptance towards EMS technology is related to technology affinity. This scale has 9 items averaged to a single overall score. The TAM items were assessed on a 7-point Likert scale (1 = "Completely Disagree" to 7 = "Completely Agree"), the ATI scale was on a 6-point Likert scale, respectively (no neutral item). Finally, study participants could express their opinion towards EMS technology using a free text field at the end of the study.

Table 3.3: Utilized TAM dimensions with the respective number of questionnaire items and scale reliability (Cronbach's  $\alpha$ ).

TAM (Bonferroni $\alpha = 0.01$ )	Items	Cronbach's $\alpha$
Perceived usefulness (PU)	3	0.698
Perceived ease of use (PEoU)	5	0.730
Attitude (Att)	5	0.694
Trust and Safety (trust)	4	0.778
Intention (Int)	1	NA

## Results

In the following, we present a detailed evaluation of the obtained results. Statistical comparisons were carried out using IBM SPSS Version 27, and results are reported as statistically significant at  $p < .05$ . We conducted non-parametric Friedman ANOVAs with subsequent pairwise comparisons (Post-hoc Wilcoxon signed-rank tests). To account for multiple tests, we applied Bonferroni correction concerning the number of TAM-sub-scales (see Table 3.3). Descriptive statistics can be seen in Table 3.4.

**Perceived usefulness (PU)** : There was a statistically significant difference in PU depending on the scenarios ( $\chi^2(2) = 86.294, p < .001$ ). Post-hoc test showed that the road safety scenario was perceived as significantly less useful than all the three other scenarios Motor Learning ( $Z = -7.075, p < .001$ ), VR ( $Z = -7.385, p < .001$ ), and media player ( $Z = -7.066, p < .001$ ). No other pairwise comparisons yielded significant differences.

**Perceived ease of use (PEoU)** : We obtained a statistically significant difference based on the scenarios ( $x^2(2) = 50.328, p < .000$ ). Again, the road safety scenario was rated significantly worse than all other scenarios Motor Learning ( $Z = -6.257, p < .001$ ), VR ( $Z = -5.152, p < .001$ ), and media player ( $Z = -5.137, p < .001$ ). Also, there were again no differences between the latter three.

**Attitude (Att)** : Friedman ANOVA indicated a significant difference in attitude depending on scenarios, ( $x^2(2) = 92.852, p < .001$ ). Just as above, scenario road safety was rated significantly worse than Motor Learning ( $Z = -6.534, p < .001$ ), VR ( $Z = -8.109, p < .001$ ), and media player ( $Z = -6.920, p < .001$ ). However, here we obtained additional differences as well: the VR scenario was rated best, significantly better than the scenarios Motor Learning ( $Z = -4.604, p < .001$ ) and media player ( $Z = -3.196, p < .001$ ).

**Trust and Safety (trust)** : We found statistically significant difference based on the scenarios ( $x^2(2) = 63.740, p < .001$ ). As in all sub-scales, the road safety scenario was perceived being significantly less trustworthy than the other scenarios Motor Learning ( $Z = -6.039, p < .001$ ), VR ( $Z = -6.721, p < .001$ ), and media player ( $Z = -6.754, p < .001$ ).

Table 3.4: Medians and interquartile range (IQR) of the TAM dimensions in the investigated scenarios.

	Md (IQR)			
TAM	Motor Learning	Virtual Reality	Media Player	Road Safety
PU	5.00 (2.00)	5.00 (1.67)	5.33 (2.17)	3.33 (2.50)
PEoU	5.20 (1.40)	5.00 (1.30)	5.00 (1.40)	4.40 (1.70)
Att	5.20 (1.90)	5.60 (1.30)	5.20 (1.60)	3.60 (3.00)
trust	4.75 (1.25)	5.00 (1.50)	5.00 (1.50)	3.75 (2.50)
Int	5.00 (3)	6.00 (1)	5.00 (2)	3.00 (4)

**Intention (Int)** : Friedman ANOVA yielded a statistically significant difference depending on the scenario ( $x^2(2) = 98.552, p < .000$ ). Study participants stated to use EMS in VR significantly more likely than all other scenarios Motor Learning ( $Z = -4.198, p < .001$ ), media player ( $Z = -3.656, p < .001$ ), and road safety ( $Z = -7.532, p < .001$ ). While there was no difference between Motor Learning and media player, the road safety scenario was again rated worst (vs. Motor Learning:  $Z = -5.783, p < .001$ ; vs. media player:  $Z = -6.518, p < .001$ ).

**Correlation Analysis** We also investigated the correlation between the scenarios and users' affinity towards technology. We found a positive co-relation between ATI score and attitude towards VR scenario ( $rs(8) = .188, p < .046$ ). Also, there is a negative

co-relation between ATI score vs. trust for road safety scenario ( $r_s(8) = -.280, p < .003$ ) and intent to use for road safety scenario ( $r_s(8) = -.287, p < .002$ ).

### 3.4.4 Interview Study

The four scenarios (descriptions and images) were shown to the participants in a randomized order in the subsequent interview study. We made it a point to make it clear to the participants to imagine each scenario technically advanced and error-free. We aimed to capture opinions and skepticism around the acceptance of the EMS technology. Our interviews were semi-structured and probed the following areas:

1. Previous experience with EMS
2. Paraphrased descriptions of the scenarios in their own words
3. Pros of the technology for each scenario
4. Cons of the technology for each scenario
5. Views on adoption or rejection of the technology for each scenario
6. Changes that should be made to encourage widespread adoption

### Participants and Procedure

The in-depth interview was conducted with 5 participants (3 males, 2 females, mean age = 28.6). The interview lasted around 1 hour and was conducted in English. Participants were first requested to complete a consent form. They were given an overview of EMS technology as well as our research. Calibration was done on the inner forearm for the flexor muscles of the wrist and fingers. We used an off-the-shelf medical compliant EMS device. We created a simple circuit with Adafruit STEMMA Non-Latching Relay and Adafruit Feather Development Board to control and modulate EMS signal. They were presented with the four scenarios after their first-hand exposure to EMS and questioned their acceptance.

### Measurement - Affinity Mapping

We categorized and sorted information using an affinity diagram (see Figure 3.15 and 3.16). We wanted to know what our participants thought of the EMS system and get information on their motivations and inhibitions. Using themes to organize the information and establish throughlines, we sought to make sense of all the notes, observations, and discoveries we captured throughout the in-depth interviews.



## Results

All relevant user quotes were grouped into two broad categories: rejection and acceptance. We had 34 prominent user quotes in the acceptance section and 50 prominent user quotes in the rejection section. To further classify them into themes, we performed a thematic analysis.

### Participants reported the following reasons for the rejection of the EMS technology:

**Unease with sensation:** Because the device acts directly on the muscles rather than the brain, it has been described as intrusive. It makes one wonder, *"Did I initiate the movement?" "Am I being controlled?"*. One participant said, *"Ok, so we are in classic lose your freedoms for the sake of the public territory."* Another one said, *"If I am not paying attention and suddenly something controls, I don't know. Still, I should need some amount of brain working. It is just a thing externally doing, stopping us"* [This finding contributes to Chapter 7, subsection 7.3: User Autonomy and Control.] Except the VR scenario, the EMS system is reported to be invasive. One participant expressed it like, *"It is a very, very direct way of interfacing"*. Another one reported, *"It is a little more invasive. Given that it is not hard to find other ways to stop people from being hit by cars like I do not know, maybe look up, have a basic amount of awareness of your environment"*. Participants expressed discomfort on two levels, with the sensation and with being controlled by the technology. One participant reported *"I did not especially like the sensation. Maybe that is something you get used to."* Another reported, *"I am not so uncomfortable with being controlled and with also the sensation of the body"*. Another said, *"I think it is a cool technology. But I do not know the side effects"*. Participants fear losing mind-body synchronization and collapsing when EMS is regulating larger muscles or stopping your body from moving. For road safety scenario, one participant said, *"Hopefully, I do not fall because everything is so connected in our body."* Another one said, *"This is my concern, it is this small thing and it just reaching my arm, if you talk about stopping whole body hopefully it will be in sync with your body."*

**Concerns around learnability:** Some of them raised concerns about how the learning will happen with such an involuntary setup. One participant reported, *"I think it is a really interesting thing if it works because I do not know if the device moves your finger, then you can properly remember the movements."* Another one argued, *"But if it was that level of discomfort for a 10 percent decrease in the amount of time that it takes to learn the muscle memory, that is not worth it"*.

**Safety and security concerns:** We told the participants to picture the technology running smoothly and without errors. Despite this, several participants voiced concerns about the EMS system's safety and security. One showed concern like *"It*

*is not learning by itself, it will follow some instructions that are already embedded. Right? It is not that it is learning from the environment like artificial intelligence, right?". Another said, "I think the more critical part is that when you think about future, what maybe could happen if some other person can manipulate and control your body."*

**Longevity:** Concerns about the unpleasant sensation, muscular impact, and exhaustion arise from prolonged exposure to the technology in certain scenarios. One participant claimed, *"Maybe you get tired quite easily. If it is like running all the time, maybe your muscles get tired quicker"*. Another said, *"There should be some limitations for using it, maybe an hour every day"* [This finding contributes to Chapter 7, subsection 7.3: Personalization and Adaptability.]

**Unlikeliness of the scenario:** The road safety scenario is unlikely to happen and is a one-time unfortunate event. In such settings, individuals are less likely to adopt the technology. One said, *"It would not be worth the amount of work I need to put in. So whenever I would step out outside of the house, I would need to think, ok, let us put these electrodes or the system on, just in case not to get hit by a car"*. Another said, *"I always see before crossing, and if I am just in the phone, I stopped watching the phone and see if there is any car. For me, maybe it would be too much"*.

**Inclination towards a traditional learning method:** Participants reported strong interest in acquiring a new skill in the traditional way. The process of trial and error, as well as incremental learning, are valued more than the result. Some of them also revealed feelings of being an impostor due to learning abilities through EMS. One participant reported, *"But if it is going to take away from that process or bypass it, that might take away the whole reason for wanting to learn it."* Another one said, *"Sure, that is going to be useful sometimes, but it is not the same experience. It is not the same enjoyment of the journey as having to learn it yourself like it is for a lot of things. And learning an instrument, I might sometimes be one of these. I think the enjoyment is that the process not necessarily the result of the process is part of it"*.

**Affinity towards technology in general:** Some participants showed a tendency to actively engage in intensive technology interaction, and some showed aversion. One participant reported, *"I would need something which does not involve my body. People should not know that I am anxious"*. Another one said, *"People are lonely in this world, so I would say just go and live with each other and not playing games and some non-serious stuff."*

**Needlessness:** The participants did not favor using muscle-controlled technologies for ordinary everyday tasks like controlling a video. They devised less intrusive methods of accomplishing the same goal. One participant said, *"I do not think this is adding something. No, I don't know. I do not think this is for me. It does not make any sense. If we are talking about in scenario of a presentation or a video. Because*

*these days we have pointers, if I want to go forward, I will click it". Another one said, "Natural gesture control seems like something cool to integrate. But the feedback, on the other hand, there seems it does not give me much payoff. It is quite invasive and probably a little uncomfortable". Learning to operate in tandem with technology may be challenging. Learning the calibration procedure for ordinary everyday chores might take a lot of time and effort [This finding contributes to Chapter 7, subsection 7.3: User Autonomy and Control.] One said, "Learning this calibration, this is one side, this is the other side. It is much work". Another one said, "I would say this will require much practice because to control the video, you need to master the gestures."*

### **Participants reported the following reasons for the adoption of the EMS technology:**

**Immersiveness:** All five participants acknowledged that the VR scenario seemed like the environment responding to their activities in the virtual world utilizing the EMS system. One of the participants said, *"Interestingly, my normal reservations of not wanting to try it.. sort of the control aspect.. fall away in this environment because it is very responsive to what you are in the VR. Like it is, you have made a choice to pick up the virtual ball, and it then feels heavy as a result."* Another participant said, *"I suppose it is because the way that I understand this, the movements my body is affected, I perceive it not as just something forcing my body to move, but rather than environment reacting back to me."* Feedback to the muscles is desirable in a VR setup since it improves the user's experience [This finding contributes to Chapter 7, subsection 7.3: Cognitive and Emotional Support.] The haptic dimension heightens the sense of immersion in the virtual environment, enhancing the user's entire experience. It piqued the curiosity of all of the participants. One reported, *"As long as the sensations are realistic or, you know, within a certain kind of bounded realism, it would be interesting."* Another one said, *"If it is really well done and you can properly simulate it without being uncomfortable, then I think it is like a good, like a cool thing to have also for video games, it would be more realistic and more fun to experience it."*

**New and fascinating:** During the research, all participants were exposed to the EMS system for the first time. The sensations and applications were unique and exciting to some of them. One argued, *"The intensity I sensed.. it is minor. I would say I was fascinated with this because my fingers were moving without me knowing it"*. Another one said, *"It is fun, just like we watch 3-D movies or something like that"*.

**Diverse range of applications:** The diverse range of applications that the EMS system can have amazed the participants. They viewed it as a bonus. One participant said, *"I think the advantage is the very diverse range of applications."*

**Ensuring safety:** By actuating the muscles at the right time, the device can boost safety in high-risk settings. Participants responded that if the stakes are high

and the technology is life-saving, they are willing to ignore the discomfort and involuntariness. One participant said, *"I was thinking like the technology will be helpful with big machinery where you can be cut.. your finger or something maybe can also be used for being not endangered in those situations."*

**Regaining muscle strength:** *The technology's strengths were discovered when it was used to assist people to overcome health problems or improve their health, for example, "This will be really helpful to people who have lost sensitivity in their muscles. It will be beneficial for them to gain grips." and "This would be nice for older people who are not able to take care of themselves" [This finding contributes to Chapter 7, subsection 7.3: Cognitive and Emotional Support.]*

**Aiding skill-building:** Some participants were fascinated by the motor learning and skill-building functionality of the technology. One said, *"But if someone is a professional musician and they already know four instruments and they just want to learn a fifth for professional reasons, and they just want to learn it quickly. Then obviously, that is a different set of needs there."* Another reported, *"For the beginners, it will be really helpful to build the confidence."* The waiver of a real instructor to learn a new skill was also considered as a benefit, particularly during the epidemic. One participant said, *"Maybe you do not even need a proper teacher, and you can learn on your own with a device that could be quite good" [This finding contributes to Chapter 7, subsection 7.3: Collaborative and Relational Design.]*

#### 3.4.5 Discussion

EMS system's user acceptance is multi-faceted, personal, and complicated (see Table 3.5). Our work highlights the extensive range of characteristics that can assist EMS designers in developing a generally recognized and acceptable system. Whereas earlier research has concentrated on the muscle-actuation capabilities of EMS while ignoring the accompanying user experience and acceptance, we provide a more nuanced understanding of this.

Overall, the following insights can be derived from this experiment concerning our research question: First, using EMS for VR was rated highest in terms of user acceptance. Participants showed a significantly higher attitude towards using VR and substantially higher intention to use (i.e., the expected behavioral outcome given by the TAM model) than all other investigated scenarios. Also, in the interview study, participants valued this use case and expressed little doubts about it (see Table 3.5).

Consequently, EMS is a promising area for VR experiences. The reason could be that haptic feedback is important for immersive VR experiences [KHF<sup>+</sup>19], yet current technology (such as haptic gloves [PVP18]) is limited to specific body parts and can still not provide sensations of heavy resistance. EMS, in contrast, has fewer limitations, which might allow providing more fine-grained sensations synchronized over multiple body parts, and has already shown promising results in this context [LYC<sup>+</sup>17b]. This was backed by

Table 3.5: Summary of identified themes and they mentions across the four scenarios.

Mapping themes across the scenarios					
Sr. No	Rejection	Motor Learning	Virtual Reality	Media Player	Road Safety
1	Unease with sensation	✓	x	✓	✓
2	Concerns around learnability	✓	x	✓	x
3	Longevity	✓	x	✓	x
4	Unlikeliness of the scenario	x	x	x	✓
5	Inclination towards the traditional method of learning	✓	x	x	x
6	Needlessness	x	x	✓	✓
Sr. No	Adoption	Motor Learning	Virtual Reality	Media Player	Road Safety
1	Immersiveness	x	✓	x	x
2	New and fascinating	✓	✓	x	x
3	Ensuring safety	x	x	x	✓
4	Aiding skill building	✓	x	x	x

qualitative participant quotes, such as *“This tech could be used in entertainment, mainly for gaming industry [...] in a very controlled and restricted fashion.”*

In contrast, the road safety scenario received the lowest scores – it was rated significantly worse than all other scenarios in all TAM dimensions. Potentially, a reason could be the safety-critical environment, as participants also stated to trust EMS significantly less in this scenario. At the same time, the potential safety gain of the use case was the only benefit of this use case as articulated in the interview statements, which was surpassed by negative factors like needlessness and a loss of control. Doubts due to low controllability were further supported by participants’ statements such as *“I would like to have complete control all the time.”* On participant during the interview said, *“I think any technology needs to be something that supplements the process rather than replaces it.”* Further, this view is also backed by the ratings of the other scenario entailing a low “sense of agency” – the motor learning scenario.

The training process to improve our sensory and motor abilities is not an easy process. To see a significant improvement, it is usually necessary to train on a task for an extended time with a high number of repetitions in a trial-and-error method. The systems based on EMS can improve our motor abilities and supplement traditional skill training. It has been demonstrated, for example, that EMS reduces users’ response time (RT) when provided prior to their action (preemptive EMS) [KNL19b]. We were surprised that,

even though EMS can speed up long and intensive learning processes, learning to play the guitar was not universally accepted, and participants expressed strong reservations. For example, one participant stated, *“yes, I would like to learn the new instrument faster. At the same time, I may want to do it all by myself. If EMS comes into the picture, I may learn quickly. But may lose on the fun of exploring the learning process.”* Another one reported that *“humans should be able to control machines for better efficiency, and not the other way round, except for the fun part.”* Thus, we conclude that scenarios, where controllability is in question, might be rejected, especially when safety-criticality becomes an additional factor. *“If we are aware of what this technology can do, if we have control over it, then it is very much beneficial”*, one participant said. Even when the technology exceeds the user’s physical abilities, it should not compromise the sense of agency and safety. In such scenarios, EMS systems must present users with alternatives to keep their sense of agency. One participant suggested, *“I think also is partly why it is jarring that it is very sort of such sudden that it is like it has happened, and you still sort of realizing that it has happened as it has already happened, whereas if it were a sort of more slow thing that would that would probably help them with the voluntariness aspect of it.”* Another one said, *“I can imagine an interface with a prompt that might be quite nice.”*

While the interview statements confirm the results of the online survey for the three scenarios VR, motor learning, and road safety (as described above), we noted a difference regarding the media player scenario. The TAM evaluation suggests that the media player scenario is similarly accepted as the motor learning use case. However, in the interviews, participants expressed various disadvantages (especially being relatively useless while concerns were raised considering its learnability and potentially unpleasant bodily sensations), while it was the only use case that received no positive reasons to foster adoption. Participants expressed apprehension about using intrusive technology for routine everyday tasks so frequently. They reported being more comfortable with a less invasive technology like a “pointer” in this case. Also, the amount of calibration and body synchronization required for the technology’s smooth operation is unnecessary and inconvenient.

Finally, we cannot confirm that a higher affinity for technology is associated with a higher acceptance of EMS systems. Only 3 of 20 potential correlations (4 scenarios \* 5 TAM dimensions) yielded a statistically significant result. The reason could be that the experience descriptors of EMS are varied and encompass both positive and negative sensations (for example, Hassib et al. (2017) have reported descriptions including ‘exciting’, but also ‘hectic’, ‘unnatural’, or ‘aggressive’ [HPS<sup>+</sup>17]). Future studies will be necessary in this regard. However, we still believe that our findings can be used as a guide to creating better user experiences for EMS-based systems.

Some participants perceived the technology as helping individuals overcome physical and mental limitations. They believed that EMS might be utilized to accomplish and traverse activities that your body could not support, especially in safety-critical scenarios: *“Maybe some people have mental issues relating to awareness, or I do not know if it is the right*

word there, but certain cognitive disabilities relating to awareness. I can imagine it would be a very useful thing.", one participant said. Another one expressed similar thoughts by "I think the road safety scenario is good for people with some medical issues or disability, if they cannot think, they have restricted movement".

### Implications

- The interplay between the system's action/reaction and the user's expectation is critical. Therefore, we recommend to adjust the system's responsiveness.
- Control is a key factor in gaining acceptance of the technology. Our findings show that users should always be in command. They should be mentally and physically prepared so that they are not caught off guard.
- The EMS system should function as a companion rather than a master.
- Users desire a sense of accomplishment as they acquire a new skill. Instead of replacing the overall learning process, the EMS system should supplement it.
- Masking the system's discomfort in the body will lead to a higher level of acceptance. Something familiar, soothing, or pleasing can be added to the sensation.
- The establishment of trust in the EMS system will be aided by transparency about how the system operates, as well as its strengths and weaknesses.
- We derived from the study that there is a trade-off between the degree of discomfort and the magnitude of the outcome. The better the result, the less concerned people are about the technology's intensity of the discomfort.
- Continuous, long-term exposure to the EMS technology has been severely questioned and critiqued. We recommend ensuring a fair amount of time between EMS technology exposures for the comfort of the users.
- The frequency of occurrence of a use-case and the importance of EMS technology in that use-case are directly related to the technology's acceptability.
- For higher potential of integration in the users' lives, we advocate simulating the overall experience as closely as possible to reality.

**Limitations and Future Work:** Given the limitations of using EMS in large-scale or early-phase evaluations, surveys were used as an exploratory method to gauge initial attitudes, concerns, and expectations. Our EMS taxonomy and the evaluation of the derived scenarios is the first step toward a systematic categorization of prototypes, and its manifestations were expressed using only a limited number of conceivable interaction scenarios. The study did not include other use cases such as user authentication, rehabilitation, or conveying affordances. As a result, we must exercise caution when

interpreting the effects. Despite larger and more diversified samples, the majority of the participants were unfamiliar with the technology, and none had ever used EMS in an interactive setting. Therefore, future investigations should consider a wider range of scenarios and participants with more experience. Further, although we believe that vignette studies that solely rely on participants' imagination are valuable in the domain of EMS too (minor differences between the survey and the interview regarding three of the four scenarios), results should be validated with real-life experiences of the technology (as shown by the media player scenario, which was rated differently in the interviews).

#### 3.4.6 Conclusion

Until now, HCI has primarily employed EMS for muscular actuation. We investigated a wide range of characteristics to acquire a better knowledge of EMS user acceptance. Our findings can aid in selecting stimulation settings when developing future interfaces, and they open up a whole slew of new possibilities for EMS use and adoption in HCI. We created four scenarios based on a literature study and assessed the technology acceptance of (N=113) participants in an online survey using the TAM model and ran in-depth interviews (N=5) to dig deeper. Our findings suggest that using EMS to enhance a VR experience is aided by a good attitude and intent to use it. As a result, we recommend that HCI researchers and UX designers leverage EMS in VR to create more engaging and immersive user experiences. Second, we discovered a rejection of the road safety scenario in both quantitative and qualitative outcomes. As a result, we recommend that HCI researchers and UX designers focus their efforts on keeping users in control of their activities rather than forcing them through EMS. We advise EMS researchers to build systems that circumvent the system's involuntary nature and provide users a sense of control. We also recommend more research into balancing the benefits of EMS in helping users learn new motor abilities faster while also allowing them to retain control: which methods, such as "wake words" or interaction modality, are most effective in maintaining control? We believe that trust development and a sense of control are the most crucial elements that systems using this technology should incorporate and explore in order to increase user acceptance and adoption of EMS. Third, we found that employing EMS to expedite learning was not widely accepted, and that the desire to keep control outweighed the desire to learn faster. This underlines the importance of providing people with choices. Based on our findings, we made recommendations that will aid HCI researchers in designing and developing products that provide appropriate experiences and are generally accepted. In the future, we aim to broaden our study to include people who have experienced EMS in lab trials so that we may compare our scenario-based results to real-life experiences. Another avenue for additional investigation is to include the viewpoints of older participants.

# Proactive Digital Detox Companion

This chapter focuses on the use of proactive companion technology for digital detox and wellness.

## 4.1 Nudgit Companion

This chapter is based on our following publication:

### Publication

Shahu, A., Melem, A., Wintersberger, P., & Michahelles, F. (2022, September). Nudgit-Reducing Online News Consumption by Digital Nudges. In Adjunct Publication of the 24th International Conference on Human-Computer Interaction with Mobile Devices and Services (pp. 1-5).

Humans spend about three hours per day on their smartphones on average [MBS<sup>+</sup>15], and there is little reason to assume that the peak of technology use is imminent, given that the installed base of Internet of Things (IoT) devices is expected to reach 30.9 billion units by 2025 (up from 13.8 billion units in 2021) <sup>1</sup>. Greater connectedness and the use of technology are both beneficial and detrimental. Especially younger people are vulnerable to “smartphone addiction” [HCK<sup>+</sup>15], suffering “excessive use, impulse control problems, and negative consequences” [PC18]. In this regard, Panova and Carbonell (2018) have argued that not all preconditions of a classical addiction are met, and the phenomenon should rather be labeled problematic or maladaptive use

<sup>1</sup>IoT active device connections, <https://www.statista.com/statistics/1101442/iot-number-of-connected-devices-worldwide/> – Accessed Dec 2024

[PC18]. Still, excessive and problematic use can lead to a wide range of negative outcomes, including social isolation, increased stress, sleep troubles, decreased performance and productivity, or time distortion [Tho18]. Especially the “always-on mentality”, i.e., being engaged in multiple conversations or media content [VKS16] entails shared attention and multitasking, which severely interferes with ongoing activities like work, study, or social relationships. According to Ko et al. (2015), excessive smartphone usage can be divided into the two categories of “frequent short usage” and “occasional extended usage” [KYL<sup>+</sup>15]. Examples of the former are permanently checking if new messages or notifications have been received, while the latter describes behaviors such as endlessly scrolling through social media feeds, continuous link-following, or playing games. The ongoing COVID 19 pandemic, as well as the resulting degree of social isolation, has increased the amount of time people spend online [CCMC20].

To counter such potentially negative consequences, some people have begun to perform “digital detox”, in other words, not to use technology for certain amounts of time. The motivation stems from desires of improving personal well-being, optimizing performance, retaining self-control, or being more present in the moment [MS18]. Researchers have already revealed that many users want to limit their time online but fail to find appropriate and successful methods to do so [LLG14]. Although there is no agreed-upon definition of the concept, the Oxford Dictionary defines digital detox as a “*period of time during which a person refrains from using their electronic devices, such as smartphones, regarded as an opportunity to reduce stress or focus on social interaction in the physical world*”<sup>2</sup>. A study done by Nekliudov et al. (2020) during the COVID-19 pandemic showed higher levels of state anxiety were associated with recent job loss and greater news intake, as well as lower than expected trust in government programs [NBC<sup>+</sup>20]. With news focused on unpleasant and troubling occurrences in the world, framing a sense of powerlessness and negative emotions, news consumption reduces mental well-being through negative hedonic experiences [BV17].

In this case study, we present an evaluation of a smartphone companion application that uses nudges to prevent users from excessively reading online news. Problematic smartphone use of continuously browsing and refreshing news articles results from the “fear of missing out” or future anxiety [SAS21] and can be considered as a manifestation of “smartphone addiction”. Nudges, in turn, can be defined as “*an intervention that steers people in a particular direction without eliminating their freedom of making the final choice*” [OSDE18a], and [WSB16a] argue that “*Digital nudging will have a significant impact on future information systems research and practice*”. One may argue that using a smartphone app to prevent excessive smartphone use appears counter-intuitive, but (1) there already exist applications for self-regulation such as *Digital Wellbeing*<sup>3</sup> or *Screen Time*<sup>4</sup>, and (2) this strategy has the potential to intervene in the problematic behavior, in the moment it occurs (“coping responses”) which has also been proved to be effective in

<sup>2</sup>Digital Detox, [https://www.lexico.com/definition/digital\\_detox](https://www.lexico.com/definition/digital_detox)– Accessed Dec 2024

<sup>3</sup>Digital Wellbeing, <https://www.android.com/digital-wellbeing/>– Accessed Dec 2024

<sup>4</sup>Screen Time, <https://support.apple.com/en-gb/guide/iphone/iph24dcd4fb8/ios>– Accessed Dec 2024

fighting against smoking addiction [FS09]. Consequently, **this work aims at answering the research question of whether an application with digital nudges can reduce news consumption on smartphones.**

#### 4.1.1 Related Work

Radtke et al. (2021) attempted to discover evidence of the favorable effects of a digital detox as an intervention strategy in a systematic study [RAS<sup>+</sup>21]. Despite the fact that various studies have been considered, the overall conclusions were rather variable, with even conflicting or contradicting findings in terms of detox efficacy. Radtke et al. (2021) attribute the range of digital detox implementations, as well as other issues such as differing assessments of identical outcomes, evaluation timings, participant selection, and randomization of study groups [RAS<sup>+</sup>21].

Therefore, we are not reinventing the wheel and, instead, drawing inspiration from Purohit et al. (2020) on the concepts of digital nudges [PBH20a]. Monge Roffarello and De Russis (2019) have divided available digital well-being assistants into two categories [MRDR19]. The authors differentiate between tracking and data-presentation categories and self-monitoring and intervention types. Interventions can take place at the phone or app level (e.g., timers and blockers), as well as through additional mechanics such as rewards or motivating quotes. We focused on self-regulation via intervention on the app level. Purohit et al. (2020) researched how digital nudges could counter the cycle of addictive design contexts employed by social media platforms [PBH20a]. We conducted similar work in the context of increasing self-awareness but with a narrower focus on online news consumption rather than social media. Schwartz (2019) presents various criticisms of the nature of self-regulation tools and claims that in certain approaches [Sch19], the tool signifies a sort of control by someone other than oneself. They propose that self-control tools should incorporate the desires of all parties involved with the tool. Likewise, Pielot and Rello (2017) discovered that the absence of push notifications has positive effects, such as making people feel less distracted and more productive [PR17]. However, it also has negative effects, as people feel less connected with others and become anxious about being unable to adhere to social norms regarding responsiveness. Hence, while being widely available by default on an impressive number of devices, self-regulation tools like *Digital Wellbeing* and *Screen Time* have yet to reach their full potential for digital health.

#### 4.1.2 Nudgit Companion - An App with Digital Nudges

While various digital detox solutions exist, such as app blockers, screen time dashboards (e.g., Digital Wellbeing on Android or Screen Time on iOS), or grayscale modes, they typically rely on restrictive mechanisms, self-imposed boundaries, or penalty nudges to reduce screen use. In contrast, Nudgit advances the state of the art by embedding subtle, content-sensitive nudges directly into users' natural browsing flow, rather than interrupting or blocking it. This proactive and context-aware approach shifts the focus

from enforcing constraints to encouraging reflective self-regulation. To monitor and control participants' news consumption behavior, we implemented an app for Apple's iOS platform (target version 15). The app acts as a host container for selected news platforms, where we aimed to provide a flow of interaction similar to the original so that user behavior within the news platform is unaffected. The app consisted of a home screen (purposely designed similar to the iOS home screen, see Figure 4.1a), where the different news apps were accessible. Pre-selected news platforms displayed their mobile web version within the application. The app can inject JavaScript into these web versions, which was, for example, necessary to hide particular articles. In addition to this basic functionality, we implemented a *nudge mode* that can be activated by users. After activating this mode, users can see additional statistics (like how many times they opened and how much time they spent within a news platform). In addition, inspired by the literature, we implemented three different types of nudges to help users reduce their news consumption [PBH20a].

**Opening-Counter:** We increased the effort to open the prototype app multiple times within the same day. Users can only open a news portal by holding the corresponding button, and the holding period is lengthened with each opening. We intended to restrict people from repeatedly browsing because the action can become burdensome if a news platform is opened frequently. We implemented an opening counter starting at zero (0) every day (i.e., the counter was reset at 4:00 am), and the news app would always open after holding the button for  $\sqrt{\text{counter}}$  time.

**Interceptor-View:** The app allowed users to set their own time limits. The interceptor-view is a full-screen sized overlay that would appear when the user's pre-set time limit is exceeded based on their usage. The overlay interferes with the user's reading flow (see Figure 4.1e) while showing usage statistics to make the user aware of the time already spent within the prototype application.

**Content-Filter:** Finally, we implemented a feature that allows users to control their news consumption with respect to particular topics. For example, if one would permanently feel the need to live check updates on "hot topics" such as the COVID-19 pandemic or the Ukrainian war, the feature allowed to simply block articles that would contain a self-defined set of keywords. These articles would then be removed from the news feed. The filter can be activated and deactivated by the user, see Figure 4.1c.

### 4.1.3 User Study

We evaluated the application as a longitudinal study over two weeks with 5 participants (2 male, 3 female, mean age = 23.4, SD = 2.6 years). We followed a purposive recruiting procedure for the participants. We shortlisted participants who spent at least three hours per week reading the news, were interested in staying up to date on current affairs, and expressed concerns about their usage patterns. First, they were briefed about the project

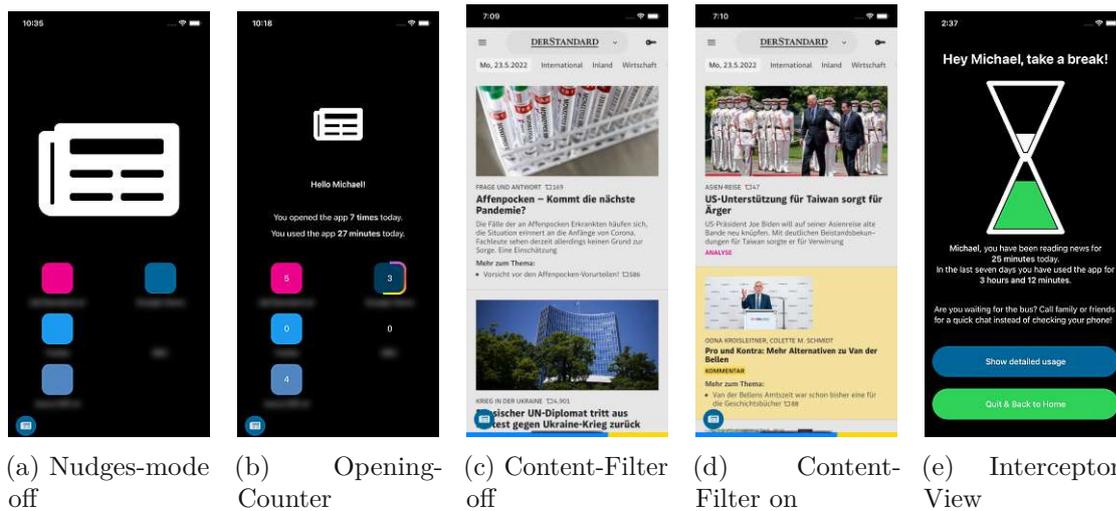


Figure 4.1: In 4.1a the home screen is shown with disabled nudges, whereas in 4.1b, the nudges are enabled, and the user is trying to bypass the *Opening-Counter*. 4.1c and 4.1d show the entry page of a news platform as soon as the user opens it with the difference that the *Content-Filter* is activated in 4.1d and hides the articles of 4.1c as they contained keywords about the Ukrainian war or the pandemic. In 4.1e the *Interceptor-View* intervenes in the user’s reading flow and draws the user’s attention to the reading time.

and signed a consent form. The two-week lasting study included three semi-structured interviews. The first interview was conducted before the app was installed on their device on day 1. After completing the first interview, participants installed the application and we explained its use in detail. They were also instructed to remove the original news apps and use the provided app instead. From the 1st to the 5th day, the app was only used to monitor participants’ news consumption behavior and all the nudges were inactive. After the second interview on day 5, we activated the nudges. Participants continued using the app with the nudges activated, and we conducted a third interview with them after 9 days (i.e., end of the 2-week study period).

## Measurements

We combined a set of objective (usage statistics) and subjective (interviews) measures for evaluation. As objective parameters, we recorded the number of times a particular news platform was accessed and the total duration the platform was viewed whenever opened (based on the foreground state of the application). This information was not only used for evaluation but also displayed to participants when the nudge modes were activated. Additionally, we recorded how often and how long the *Content-Filter* was activated, as well as the number of times the *Interceptor-View* was displayed. Additionally, three rounds of interviews were done at various stages of the experimentation process:

**First Interview:** In the first interview, participants were asked about their smartphone usage, online news intake, and feelings regarding digital detox. The initial interview took place for about 25 minutes.

**Second Interview:** The second interview was held for 15 minutes. Participants were asked to identify any terms in the articles they read that may have lowered their mood. During this interview, the app's nudging functions were activated. Then, participants were emphasized to set their own *time limit* and *reminder time*, which varied depending on the participant's prior usage over the first five days. The *time limit* was suggested to be set to 30% lower than the average usage and the *reminder time* for one-third of the *time limit*. However, when asked whether they agreed with such values, two of the five individuals proposed using higher numbers. Furthermore, they were shown how to add and remove keywords, how to activate and deactivate the *Content-Filter*, and how it functions.

**Third Interview:** In the final interview, participants were asked in-depth about their experiences with the prototype app. It was interesting to see how they viewed the nudges and how it influenced their news consumption and use of the prototype app. Further inquiries focused on the impact of utilizing the prototype on the participants' well-being. The session lasted about 30 minutes.

### 4.1.4 Results

A Wilcoxon signed-rank test showed that 9 days of nudges did elicit a statistically significant change in how many times participants opened the app ( $Z = -2.023$ ,  $p = 0.043$ ). In the first phase of the study, participants opened the app more frequently (Mdn = 8.8) compared to the second phase when nudges were activated (Mdn = 5.2). Additionally, the time spent on the news platforms decreased from a median of 18 minutes in the first phase to 11.3 minutes in the second phase. We used the thematic analysis method to categorize and sort interview data. We wanted to investigate how the nudges were perceived by the participants and how they felt about using the prototype application. The core team consisted of three researchers (one female, two males) with experience in HCI. We used an online whiteboard tool (Miro) to facilitate discussion and categorization. The themes that emerged from the collected data are as follows:

**Existing usage pattern:** *We found that participants read the news the most when they are bored or have a lot of free time and nothing planned [This finding contributes to Chapter 7, subsection 7.3: Personalization and Adaptability.]* One participant reported "When I have a lot of free time, it tends to be more." They stated that they frequently open news apps while commuting. Another participant said "On the bus or in public transport, I always have the cell phone in my hand or I just listen to music." They would also use the news app out of habit. The initial interview was mostly used to gather the information, which was later verified.

**Urge to stay in the know:** We discovered that our participants valued knowing what was going on. *They desired the information in order to have engaging conversations in their social circles [This finding contributes to Chapter 7, subsection 7.3: Collaborative and Relational Design.]* One of our participants said *"I feel well-read, I feel good because I feel like I am up to date and I am not missing anything."* And, in the early days of using the app, some of them deactivated the app's content filter feature on specific occasions like *"In the beginning, I deactivated the filter quite often, but then I didn't actually do that anymore because I realized that it doesn't hurt if I just don't read some of the information. I think that made me feel better [This finding contributes to Chapter 7, subsection 7.3: User Autonomy and Control]."*

**Self-awareness:** All of the participants stated that they became aware of how much time they spend on the news app every day. One participant said *"It was a bit weird when you thought 'Have I really pressed it that many times?'"* They also discussed their reading habits and how it affected their mood for example one said *"I think this is a good idea, especially if you fall into such a pattern that you read articles after articles on a topic and know exactly that it is not good for you to read these articles because that doesn't really change anything."*

**Support in detox:** All three nudges assisted our participants in reducing their news consumption. For the opening counter feature, one of our participants said *"I think that would have been more of a signal for me to say 'okay, I've opened it eleven times today, now I should put it away.'" Another reported for the Interceptor feature "I think the quotes were pretty cool because they made me call someone a couple of times." Some participants were able to calm down and unwind as a result of the content filter [This finding contributes to Chapter 7, subsection 7.3: Cognitive and Emotional Support.] One reported "I realized that hiding news from Ukraine and Russia doesn't affect my life badly. Before that, it was influenced by negativity and bad vibes" [This finding contributes to Chapter 7, subsection 7.3: Cognitive and Emotional Support.]*

**Well-being:** Some of them voiced their views on how certain issues and news stories affect their general well-being. The Ukraine war and COVID-19 were two of the biggest themes. One said *"I have to say it's gotten a lot better. So before using the app, the flood of data from the Ukraine war was very high and with the app, it was contained a bit."* Both the initial and final interviews yielded this data.

#### 4.1.5 Discussion

We conducted an in-the-wild study to capture participants' usage data and experiences to examine the results of digital nudges in the context of online news consumption using our companion app. We discovered that using our app promotes self-awareness leading to reduced usage. The nudges made them aware of how frequently they used the app and how much time they spent on it, allowing them to establish their own time limit

and feeling in control of their usage. This is consistent with the findings of Purohit et al. (2020), where digital nudge interventions made users mindful of their actions in the context of social media [PBH20a]. After employing the content filter, some participants reported feeling more "contained". It assisted them in filtering out the news that they found distressing. Unlike prior work by Schwartz (2019), where online self-regulation tools seemed like they were controlled by someone other than oneself, participants of our study claimed to be more in charge of their own activities by setting limits and reminders [Sch19]. In comparison to *iPhone Screen Time*, the nudges of the prototype application are less strict and the users can decide how often they want to be notified. One participant stated *"In contrast to the iOS function, where you are only made aware of your usage time at the end, it was so that you had a better overview of how much time you were already spending on the page while reading."* Another participant reported *"I think it's a good thing that you can't turn it off at all, because with iOS Screen Time I just press "No limit today" and I don't care anymore."* We discovered a considerable change in app opening and usage before and after using the prototype app. Participants opened the individual news apps significantly less often when the nudges were active, and also the average duration declined (we argue that given the difference in the medians, the results could be likely significant with a higher number of study participants). Based on our findings, we recommend creating systems that allow users to define their own goals and receive reminders about them. With respect to the news reading behavior, users should be able to select and reject a topic that they find compelling and distressing. However, we cannot comment on the support for the formation of sustainable behavior because this requires a broader investigation.

### 4.1.6 Conclusion and future work

We identified that the quantity of time and type of news consumed has a negative impact on our participants' overall well-being. It is consistent with the prior findings of Nekliudov et al. (2020) and Thomée (2018) [NBC<sup>+</sup>20, Tho18]. Digital nudges delivered via our app made participants more mindful of their behavior, resulting in successful behavior modification throughout the study. Content filtering assisted them in removing distressing content and feeling more tranquil. The opening counter was reported to raise awareness about how frequently they visit the app. As soon as the previously established time restriction was breached, the interceptor view alerted them. Some participants described it as both unpleasant and effective. The statistics also reveal that the overall app utilization is lower after nudging. Some participants expressed an interest in continuing to read news through our app in order to maintain track of their behavior. Some expressed an interest in doing the same to social media apps like Instagram. We believe it is a solid starting point for introducing digital nudges into the smartphone environment. The study's limitation is the number of participants. For future work, we would like to investigate the impact of having a larger number of participants use our companion app for a lengthy span of time. We are also interested in how our ideas extend beyond news apps and compare to social media apps. Also, how nudging can aid across platforms such as tablets, PCs, and smart TVs is also an intriguing area of research.

## 4.2 Watchful Detox Companion

This chapter is based on our following publication:

### Publication

Shahu, A., Pechstein, F., & Michahelles, F. (2024). Beyond Screen Time: Exploring Smartwatch Interventions for Digital Well-Being. In *Proceedings of Mensch und Computer 2024* (pp. 83-98).

As we delve deeper into the digital era, we witness an increasing number of individuals engaging with available technologies. However, this heightened interaction often poses risks to mental and physical well-being, as well as social relationships [SH16, YFLL20, BM21b]. The pervasive availability of information and connectivity has led to a rise in perceived mental strain and stress. According to data from data.ai <sup>5</sup>, users worldwide spent an average of 4.8 hours per day on their phones in 2022. Notably, social media, photo, and video apps accounted for 70% of this time, aligning with predictions. This trend further highlights the dichotomy between Landes' concept of "my time," now categorized into "consumption time" versus "personal time," albeit with blurred boundaries [Bro84]. Consequently, digital detox practices have gained widespread popularity.

Digital detox tools often come equipped with a variety of functionalities aimed at supporting users who are finding it hard to disconnect. Popular choices are smartphone applications, such as *Digital Wellbeing*, which comes with Android devices, *Screen Time*, which comes with iOS, or other various applications found in Google's Play Store or Apple's App Store. Adjusting one's habits to reduce digital consumption is inherently challenging due to the complexity of altering behaviors [MRJ<sup>+</sup>13]. There are numerous ways to achieve a digital detox for smartphone addiction, spanning from basic guidelines to elaborate technical aids designed for tracking, controlling usage, and limiting apps, along with providing rewards for reduced screen time [MRDR19, MRDR23]. According to research by Lyngs et al. (2019), digital detox tools typically incorporate four main types of features to foster changes in behavior [LLS<sup>+</sup>19]: the ability to block or remove distractions, self-monitoring capabilities, mechanisms to support progress toward goals, and systems of rewards and penalties. Albeit the array of features offered by digital detox applications to help users, an intriguing dilemma presents itself. Why use smartphone technology—the very thing from which one is attempting to detach—as a means of regulation? Or as Monge Roffarello and De Russis (2023) put it: *“digital devices and services are, at the same time, the source of the problem and the platform with which the interventions are delivered to the user.”* [MRDR23] There is another piece of technology that is close to the smartphone and that can be a viable platform.

Smartwatches have emerged as the next big innovation following smartphones [JKC16, RPP14], with sales reaching 134 million units in 2023 and expected to grow by nearly

<sup>5</sup><https://www.data.ai/en/go/state-of-mobile-2022/?consentUpdate=updated> – Accessed Dec 2024

30% over the next five years<sup>6</sup>. These devices have the potential to transform how users engage with their phones and may help lessen dependence on them [CCB15]. By serving as a bridge between the user and their phone, smartwatches allow for interactions that demand less of the user's attention, assisting with small tasks and providing quick access to information [VSVB<sup>+</sup>17]. In spite of these benefits, there are currently few<sup>7</sup> examples showcasing the application and effectiveness of wearables or smartwatches in facilitating digital detox. A systematic review by Monge Roffarello and De Russis (2023) investigating current work on digital self-monitoring tools lists no approach that makes use of smartwatches [MRDR23].

In this case study, we explore the design and implementation of digital detox interventions using smartwatch technology as a companion to help users become more aware of their device usage and reduce screen time. Given the advanced functionalities and feedback mechanisms of contemporary smartwatches, numerous intervention designs are viable. A key advantage of a smartwatch is its wrist-mounted display or interface, often referred to as the *watch's face*. This placement facilitates quick interactions and enables users to easily view information with minimal cognitive strain. Smartwatches also present promising avenues for influencing physical activity behaviors and enhancing health consciousness among users [SAVL<sup>+</sup>16, GMvO<sup>+</sup>18]. Given the availability of tracking data for physiological metrics, physical activity, and phone usage, we propose the following research questions:

- **RQ 1:** How could smartwatches support digital detox and reduce smartphone screen time?
- **RQ 2:** Can health-data recordings meaningfully complement smartphone usage data?
- **RQ 3:** How might we redesign interventions to reduce screen time based on these findings?

### 4.2.1 Background

We delved into the literature on digital overload, habit formation, and implementations and designs of smartphone-based applications to help with screen-time reduction.

#### Excessive digital device use

The design of smartphone applications, characterized by easy accessibility, engaging interfaces, algorithms that deliver endless relevant content, and gamification features, encourages prolonged use. Excessive and frequent use of mobile devices, and social media

---

<sup>6</sup>Smartwatch market statistics, <https://www.mordorintelligence.com/industry-reports/smartwatch-market> – Accessed Dec 2024

<sup>7</sup>e.g. RSW-TIME OFF!, <https://rudolphschellingwebermann.com/en/projects/off—> Accessed June 2024

have been linked to influencing mental and physical health [YFLL20, SS<sup>+</sup>18, BCF16], sleep [SPA<sup>+</sup>15, SKR<sup>+</sup>21], and academic performance negatively [AB20, SPA<sup>+</sup>15]. The primary reasons behind the widespread engagement with digital devices, such as smartphones and online content, internet addiction, and social media usage, are still under debate and cover research from diverse areas, such as psychology, addictive behavior and disorders, and HCI [KG11, BMLF<sup>+</sup>15, MRDR23]. While there is an ongoing discussion about the roots of addictive behavior, there is a general agreement that therapy could focus on either abstinence or moderated use, among other strategies. This leads to the concept of 'digital detox' as a method for managing excessive digital device use. As concerns over digital consumption grow, tools to monitor, regulate, or limit device use have been introduced. Ultimately, the responsibility falls on individuals to cultivate awareness of their device use and to integrate these tools into their daily lives [NVPK23]. A systematic review by Radtke et al. (2022) sought to evaluate the effectiveness of digital detox interventions [RAS<sup>+</sup>22]. After reviewing numerous studies, they found mixed and often conflicting results on the success of digital detox efforts. The diversity in digital detox implementations, differences in measuring outcomes, timing of assessments, selection of participants, and the randomization of study groups were cited as reasons for these inconsistent findings. Other limitations highlighted by the authors include the lack of device-based measures of user behavior, which would allow for a more reliable assessment than self-reported behavior.

Despite the awareness of digital well-being applications, a significant portion of users either stop using them after a while or never start at all. Parry et al. (2023) while investigating the adoption rate of digital detox applications [PIRM<sup>+</sup>23], found that although 80.48% of their participants indicated that they are aware of digital well-being applications, 63.06% of those respondents indicated that they have ceased using (16.12%) or have never (46.94%) used such applications. The mixed outcomes of digital detox efforts and the varying impact of social media on mental health highlight the nuanced relationship between digital device usage and user wellbeing. As the digital landscape continues to evolve, there is a pressing need to diversify the strategies and tools available for individuals seeking to manage their digital consumption effectively.

### Digital habit formation

A habit refers to the predisposition to engage in a specific behavior, with habitual behavior stemming from this tendency [NWQ06, PVCB18]. While individuals may be aware of their actions, they often lack insight into the habit's mechanics, rendering change difficult [VVR18]. Dual system theory offers an explanation for how impulses emerge and decisions are made, distinguishing between two cognitive pathways: System 1 operates unconsciously, quickly, and in parallel, relying on automatic responses, learned habits, and heuristics. System 2, in contrast, is slower, conscious, and driven by goals, intentions, and rules, playing a critical role in planning, decision-making, and resisting habits and temptations. For a new, desirable behavior to become habitual, it must transition from a System 2 to a System 1 process [Dan17, LLS<sup>+</sup>19].

In the realm of digital detox, various strategies have been proposed to alter habits. Pinder et al. (2018) suggest employing intentions and automation of self-regulation in habit formation [PVCB18]. Monge Roffarello and De Russis (2019) categorize digital well-being assistants based on their features into self-monitoring and intervention-based approaches [MRDR19]. Despite the prevalence of tracking and data visualization in these applications, intervention features are less common, highlighting the diverse tactics each self-control tool employs. Following an exploratory study, the development of a well-being assistant revealed that although self-tracking is crucial for behavior change, it seldom fosters lasting behavioral modification [MRDR19]. Upon removal of the monitoring tool, individuals often revert to their original behaviors. This finding highlights the importance of grounding digital well-being tools in habit formation research to ensure sustained adherence to healthy digital behaviors [MRDR19]. Similarly, [LLS<sup>+</sup>19] analyzed Android and iOS apps and browser extensions serving as digital well-being and detox tools, examining their implementation of dual system theory [LLS<sup>+</sup>19]. While using different methodologies and classifications compared to Monge Roffarello and De Russis (2019), the analysis of feature distribution shows some degree of alignment [MRDR19]. However, Lyngs et al. (2019) identify a lack of features aimed at habit scaffolding rather than mere blocking. Furthermore, they noted a lack of delay mechanisms and expectancy components, which gauge a user's perceived likelihood of achieving their objectives [LLS<sup>+</sup>19].

#### Digital self-control tools

Over the years, a myriad of digital tools and companion applications have emerged to assist users in their quest to reduce application screen time, support self-monitoring, and block application use. In 2013, Löchtefeld et al. (2013) released an app called *AppDetox* in the Android Play store [LBG13]. The features provided were: One would allow users to define time frames in which opening a particular application was restricted. Breaking a rule was recorded and displayed in a separate overview. In 2016, Hiniker et al. (2016) proposed the app *MyTime*, which tried to support people in achieving goals related to smartphone non-use [HHKK16]. Three intervention nudges were implemented: First, users were asked what they wanted to accomplish today, then they could select from a catalogue of all installed applications the apps they wanted to track and set a timer for maximum daily usage. Whenever one of the tracked applications was launched, a live notification in the status bar displayed a progress bar showing how much time the user had spent with the application in relation to the set limit. When a limit was reached, a UI overlay displayed the set limit and the defined goal for the day, suggesting an alternative to using the phone. The timeout feature was partly used to gain information about usage, which was reflected in how users reacted to the 'time's up' notifications. However, participants reduced their use of applications that they perceived as 'wasting time'. With iOS 12, released in September 2018, Apple added *Screen Time* to the roster of built-in system features. With this application, it became possible to get detailed usage information, block or limit time spent with certain apps, and even get weekly reports about usage trends in iOS. Starting with 2018, Android likewise got a built-in application

called *Digital Wellbeing*<sup>8</sup> responsible for various aspects of digital detox. Dashboards and overviews provide information on daily and weekly app usage, phone unlocks, and receive notifications by app. Historical data was accessible only up to four weeks, although it's possible to programmatically gather aggregated data for more extended periods in lower time resolution. The application is capable of providing settings for time limits for apps. After exceeding these goals, the app or URL will get blocked and can't be used for the rest of the day unless the limit gets removed. Given how deep third-party apps need to be integrated into systems to support restricting features, providing default built-in tools in the commonly used mobile operating systems can be seen as a sensible strategy to ensure users' privacy and security.

Okeke et al. (2018) created an application for Android called *GoodVibe* that provides users with real-time, textual feedback on how much time they have spent on a mobile application [OSDE18b]. Furthermore, a digital nudge in the form of gentle phone vibrations when a specified daily usage limit for an app is reached was added. Kim et al. (2019) own application *Goalkeeper* employed several different mechanisms and proposed comparably more substantial restrictions on their users [KJKL19]. Standard features like a timeline, the capability to define time limits for applications (daily and weekly limits are supported), and utilizing the notification bar to provide quick access to usage information were included. The authors, furthermore, introduced a break and lockout mode during which only basic phone functions can be accessed. A break mode could be started voluntarily and stopped at any given time, whereas lockouts were triggered after exceeding defined usage limits for applications. Monge Roffarello and De Russis (2019) implemented *Socialize* after reviewing 42 available digital detox applications using features that were present in at least 15% of these apps: tracking, data presentation, timers and contextual interventions [MRDR19]. Although using *Socialize*, participants constantly checked their phones, they still managed to reduce the time spent on social media significantly. However, interventions were rarely used, and even the use of *Socialize* did not change how they perceived problematic phone use. Purohit and Holzer (2021) experimented with iOS *Shortcuts* application to create nudges to reduce the use of Instagram [PH21]. Shortcuts allow users to program tasks without knowledge of any programming language and can thus theoretically be used with any app or content. The authors see the benefit of ensuring privacy and ethics by using this approach with built-in resources and mechanisms.

### Challenges of self-control tools and nudges

Thaler and Sunstein (2008) define a nudge as a subtle feature of choice architecture that predictably influences behavior without restricting any options or significantly altering economic incentives [TS08]. Essentially, nudges gently guide individuals towards healthier choices by making those options more accessible, such as placing a basket of free fruit next to a snack machine as an encouragement for healthier snacking. Digital nudges, as described by Weinmann et al. (2016), use interface elements to subtly guide user

<sup>8</sup>Digital Wellbeing-<https://www.android.com/digital-wellbeing/>-Accessed June 2023

behavior in decision-making scenarios, leveraging the design of the choice presentation to influence decisions unconsciously, in line with dual-process theory [WSB16b]. Simple changes, like altering default settings, have been shown to significantly impact choices, demonstrating the power of choice architecture [MVS16].

Building habits, according to dual-system theory, involves transitioning behaviors from conscious, deliberate actions (System 2) to automatic, subconscious processes (System 1). However, developing new habits, particularly those related to health and activity, can take months to solidify and might demand nudging. *mHealth* user studies implementing interventions to promote more active lifestyles describe three to six months until exercises become habitual behavior [LVJPW10]. The challenge lies in maintaining engagement without the interventions becoming burdensome to the point of abandonment. Schwartz et al. (2021) propose strategies to minimize the risk of users abandoning digital well-being tools, including adjustable interventions, combining different strategies, offering user control over chosen interventions, and ensuring consistent engagement in defiance of technological changes [SMRDRA21]. Kovacs et al. (2018) also suggest rotating interventions to keep users engaged, acknowledging that users may eventually overlook static nudges [KWB18]. However, nudges' effectiveness can vary, with their impact dependent on the context and how they're implemented [MVS16]. The ethical dimensions of nudging, particularly regarding digital detox efforts, raise concerns over privacy, control, and the potential for manipulation, highlighting the importance of designing nudges that are transparent, easily opted out of, and genuinely aimed at improving user well-being [Tha18, GLAO23, Mil23, PBS<sup>+</sup>23]. Critiques of self-control tools highlight the necessity for a balance between user desires and the objectives of tool designers, platform owners, and application developers [Sch19, SMRDRA21]. Ethical and usability concerns must be addressed to ensure that digital nudging tools enhance user autonomy and experience without encroaching on privacy or free choice [PBH20b, PH21]. Therefore, while digital nudges and self-control tools offer promising avenues for encouraging healthier digital habits, their design and implementation must carefully consider user acceptance and the subtle balance between guiding and controlling user behavior. Monge Roffarello and De Russis (2023) found in their systematic review that current digital self-control tools include a lack of theory and, in general, disregard ethical implications and issues [MRDR23]. Secondly, the prevalent short-term evaluation leaves their performance in terms of building long-term sustainable habits up to speculation. Furthermore, the authors propose based on the review that future research might look into overcoming a limited perspective that focuses on technology overuse and self-monitoring tools and finally find a way to deal with the business models of big-tech enterprises, that benefit from the continuous and frequent usage through their users and clients [MRDR23].

#### **Towards Wearables**

Wearable devices, including smartwatches, have played pivotal roles in research focused on behavior change interventions, such as encouraging more active lifestyles among sedentary individuals [SPA<sup>+</sup>15, SP13, MPV<sup>+</sup>16]. Wearable technologies offer two primary

health-related applications: they can proactively correct unhealthy behaviors to prevent diseases, or they can provide diagnostic support by continuously monitoring and analyzing biomedical signals to detect medical conditions [MSKRJ17]. These devices incorporate a variety of compact sensors capable of tracking critical physiological indicators, including heart rate, oxygen saturation, blood pressure, skin temperature, respiration rate, and skin conductance [MSKRJ17, PB09]. Additionally, wearables can be equipped with sensors to measure movement via accelerometers and gyroscopes and other environmental factors, such as orientation through magnetometers, location with GPS, and atmospheric conditions using barometers, humidity sensors, temperature gauges, and light sensors [MSKRJ17]. Raw sensor data collected by wearables can be processed and analyzed directly on the device, and then transmitted to other devices or cloud services for additional processing or storage. This analysis includes interpreting sensor signals to identify medical conditions or detect physical activities such as gait, step count, sleep patterns, and more, directly within the device [Udd19].

Wearable technology encounters several challenges that can affect user adoption, one of which is the precision of sensor data or the accuracy of recognition outcomes. For example, Svensson et al. (2019) investigated the reliability of sleep cycle detection by the Fitbit Versa smartwatch, comparing its readings against those from a validated single-channel EEG system across two weeks of nightly data from 20 participants [SCT<sup>+</sup>19]. Although there were no significant differences in the measurements of time spent in bed and overall sleep duration, discrepancies arose in the estimation of time spent in deep sleep and awake periods, with the smartwatch both significantly overestimating and underestimating these phases. Regardless of these variances, Svensson concluded that the sleep tracker could still be useful for measuring sleep duration in longitudinal studies, albeit with certain caveats [SCT<sup>+</sup>19]. Integrating data from various devices or sources to assess mental state, mental health, stress, and sleep quality is a well-established practice.

Sano and Picard (2013) combined accelerometer and skin conductance data from wearable sensors with mobile phone usage data to gauge overall health, mood, and stress levels [SP13]. In a separate study, they gathered information from wearable sensors and phone data, as well as self-reported sleep scores and personal characteristics, to identify factors influencing academic performance, sleep quality, stress, and mental health [SPA<sup>+</sup>15]. Massar et al. (2021) have shown that data from wearable sleep trackers, phone-based tappigraphy (analyzing interaction patterns), and self-reports provide both overlapping and unique insights into sleep behavior [MCS<sup>+</sup>21]. While tappigraphy doesn't directly measure screen time or app usage, it offers indirect estimates of daily screen exposure. Past research utilized physical activity and sleep data from smartwatches, along with screen time data, to evaluate sleep quality and behavioral health, proposing methods that predict sleep quality with a high accuracy of 91%. These studies underscore the potential of combining wearable technology and digital usage data to enhance our understanding and management of health and well-being [ACB21, ACB22]. Although advancements in wearable technologies for health monitoring and behavior change have been made, there's a significant gap in accurately integrating and analyzing data from various sources to

fully understand health states. Furthermore, combining data from wearables with other sources to assess behavior, mental health, and sleep quality is a promising direction for digital detox. Furthermore, to add to this regard, findings from Cecchinato et al. (2015) suggest that using smartwatches helps users manage their availability and can reduce the time spent on other devices [CCB15].

### 4.2.2 Concept and Prototype development

Based on the literature review, we propose the following intervention approach:

#### Intervention Design

Drawing from the findings in the literature and an examination of existing reference applications, intervention designs were developed, largely inspired by the methodology outlined by Okeke et al. (2018) in their work [OSDE18b]. Studies that emphasize the effectiveness of self-monitoring and ambient feedback in promoting reflective action, such as digital nudging [SMWM22] and lightweight tracking interfaces [LSE21], influenced our decision to use wearable collected indicators such as screen unlocks, app usage times, and ambient prompts. Building on these findings, we introduced contextualized visual feedback (e.g., personalized graphs and gentle reminders) to support user autonomy without overwhelming them.

**Platform selection for phone and watch:** The mobile OS market <sup>9</sup>, once diverse, is now dominated by Android (approximately 68% market share) and iOS (around 30%). For this research, Android was chosen due to existing development experience, especially since both platforms offered necessary APIs: iOS with its Screen Time API since iOS 15<sup>10</sup> and Android's UsageStatsManager since Android 5.0 Lollipop <sup>11</sup>. Choosing a smartwatch platform involved evaluating options like Garmin, Suunto, Tizen, and Wear OS. Even though initially Garmin was considered as the development platform for its simplistic and features and health & sports focus, limitations in phone-watch communication led to selecting Wear OS for its seamless integration with Android. The Suunto 7 model, running Wear OS 2.5 and equipped with Google Fit, was chosen for its compatibility and comprehensive Google-backed software ecosystem, promising well-documented integration and testing.

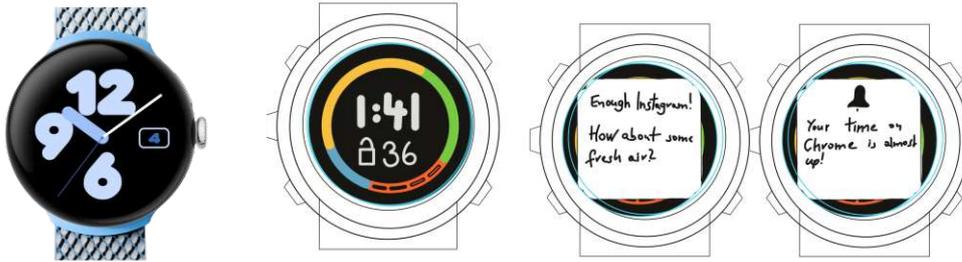
**Watch face:** Displaying information directly on the watch face offers a straightforward and efficient means of delivering data to the user without significant interference or distraction, as illustrated in Figure 4.2a. This approach is common across various

---

<sup>9</sup>Mobile Operating System Market Share Worldwide, <https://gs.statcounter.com/os-market-share/mobile/worldwide>—Accessed May 2023

<sup>10</sup>Screen Time API, <https://developer.apple.com/documentation/DeviceActivity>—Accessed May 2023

<sup>11</sup>UsageStatsManager, <https://developer.android.com/reference/android/app/usage/UsageStatsManager>—Accessed May 2023



(a) Standard watch face of the Google Pixel 2 watch<sup>12</sup>. (b) Draft of the proto-type “watch face”. (c) Early draft of the “alarm nudge”-intervention on a watch.

Figure 4.2: Watch face example and early sketches.

types of watches capable of processing data, encompassing applications in the medical field (such as blood sugar levels and heart rate monitoring), sports, daily activities (like notifications or navigation), and even entertainment (games). Watch faces possess specific characteristics that can complicate the display of sensitive information: they are openly worn and designed for quick readability. Yet, for non-standard watch interfaces, like a highly customized watch face, the data may only be interpretable to an informed observer. Accordingly, adopting the design principles outlined by Jafarinai et al. (2005) in their development of Breakaway—a smart sculpture placed in a public space to encourage taking breaks from sitting too long—we used the following logical components to design the watch face [JFHZ05]:

1. **Abstract:** We display only aggregated application data and usage totals.
2. **Non-intrusive:** Watches and their faces are unobtrusive by design.
3. **Public:** Data is glanceable only by the informed user as color mappings are unique for each user. However, total usage time can be problematic but is required.
4. **Aesthetic:** Customization options are available through complications and coloring schemes.

The watch face functions as a source of near real-time feedback for the user throughout the day, independent of phone use, thereby enhancing awareness of their device usage. Figure 4.2b shows an early draft of this intervention. The watch face is subject to the greatest number of constraints, in line with the design principles for Google’s WearOS<sup>13</sup>. Therefore, given that the face serves as the primary interaction hub, it is logical to extend certain design elements to the phone application. By presenting information in consistent

<sup>12</sup>Google Pixel 2, [https://store.google.com/gb/product/pixel\\_watch\\_2](https://store.google.com/gb/product/pixel_watch_2)—Accessed January 2024

<sup>13</sup>WearOS design principles: <https://developer.android.com/design/ui/wear/guides/foundations/design-principles>—Accessed August 2023

formats across various interfaces, it simplifies the process of assimilating combined data, thereby minimizing cognitive effort. The circular design, which is a prominent feature in the initial touchpoints of both the watch interfaces, is reused in other elements to enhance design consistency. This approach is evident in the appearance of the time doughnut and the alarm-input-slider, as illustrated in the respective Figures 4.3c and 4.3d.

**Alarm nudge:** Our objective is not to develop an entirely new approach. Rather, we are drawing inspiration from the concept of digital nudges [PBH20a, SMWM22]. Purohit et al. (2020) research focused on exploring ways in which digital nudges might challenge the addictive design contexts commonly employed by social media platforms [PBH20a]. The design also borrowed elements from Okeke et al. (2018), approach, utilizing vibration as a discreet nudge on the watch [OSDE18b]. This occurs when the user exceeds a predetermined amount of daily screen time, prompting them to divert their attention from their phone and reconsider their usage patterns. To ensure the user’s focus shifts from their phone, the vibration notification can only be dismissed on the watch itself. If the user persists in using a specific app beyond the daily limit, the reminder will activate once more. Accompanying the vibration is a message displayed on the watch, stating:

You have been using “<application name>” longer than you intended.

This message was crafted to be straightforward and neutral. Unlike the specific limits set by Okeke et al. (2018) for Facebook usage, participants have the flexibility to establish their own limits for any app they wish to use less, encouraging a personalized approach to digital well-being [OSDE18b]. Early drafts of how this visual nudge might appear on the watch are illustrated in Figure 4.2c.

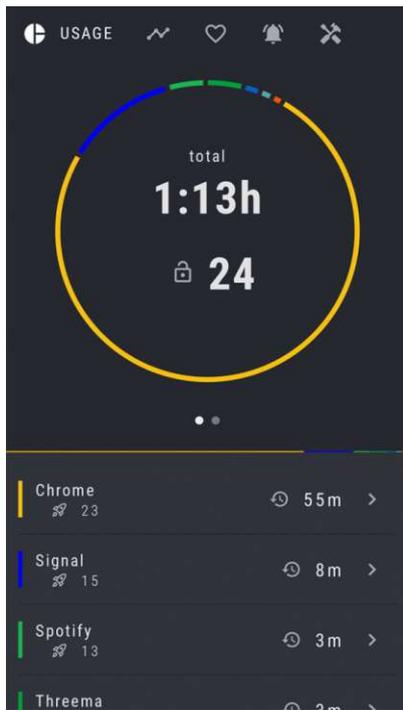
**Color consistency:** Colors serve as a key source of information, indicating which application was utilized in summaries and visualizations, as well as the duration and timing of its use. To maintain clarity and coherence, it’s imperative that color mappings remain unaltered and consistent across all interfaces on both the phone and the watch. This consistency is maintained by creating a registry of all apps and assigning a color code that matches the primary color of the app’s icon. Examples of how this color consistency is implemented across various devices, offering a unified view through the same application and color mapping scheme, are illustrated in Figure 4.4. Furthermore, color is incorporated as an additional attribute in all synchronization or alarm notifications to ensure uniformity across all connected devices.

#### Watchful phone companion application

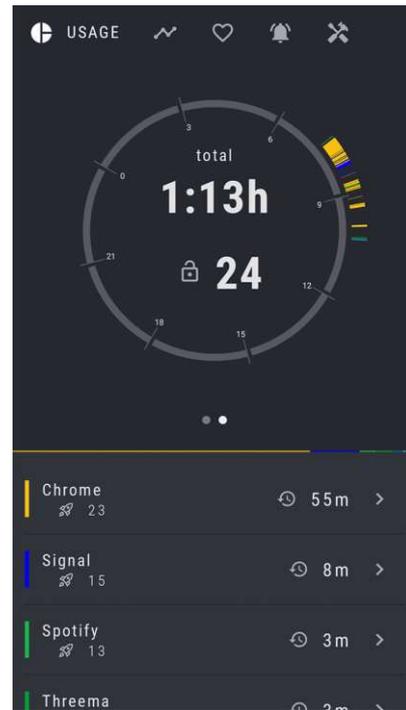
**Technical design:** To ensure optimal user experiences, we adhered to Google’s guidelines for modern Android development<sup>14</sup> across all aspects of our development. The app

---

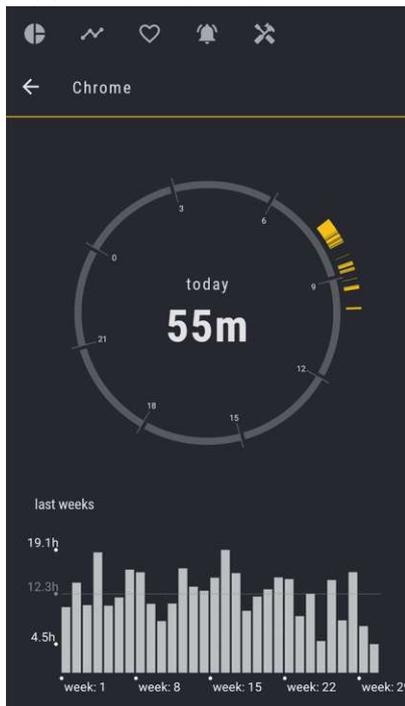
<sup>14</sup>Modern Android Development, <https://developer.android.com/modern-android-development>–Accessed July 2023



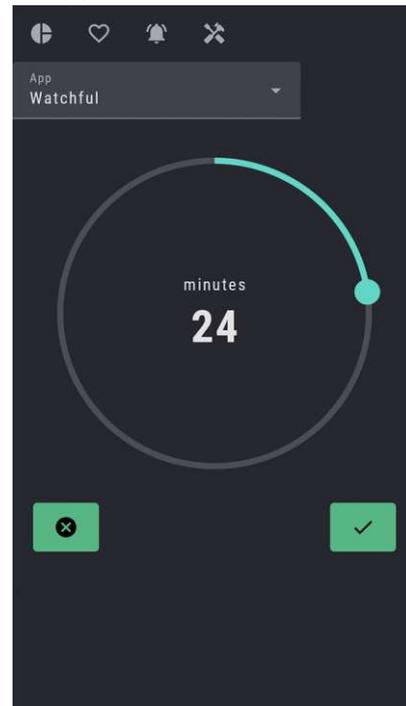
(a) Total daily usage overview



(b) Daily historic overview



(c) App-specific view



(d) Configuring alarms

Figure 4.3: User interface of *Watchful* Application.

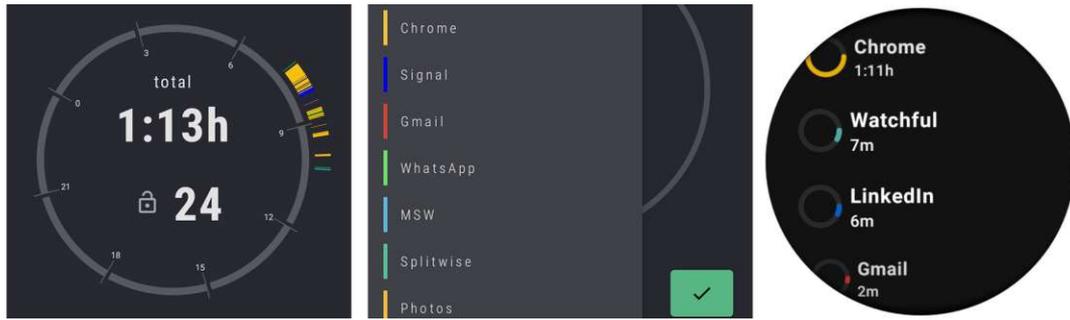


Figure 4.4: Color consistency per application across views and devices.

was developed in *Kotlin*, utilizing a single-activity architecture complemented by modular components for respective features. The UI design was inspired by Google’s Rally, a material design study<sup>15</sup> and is implemented in Jetpack Compose. Data persistence was managed with *Room*, providing a sophisticated layer over SQLite to store app and phone usage data collected from the Android system’s StatsManager API. This data served as the foundation for the app’s backend, enabling UI interactions. To achieve a cohesive data presentation, a unified format was created using *Kotlin dataframe*<sup>16</sup>, facilitating straightforward statistical calculations and implementing graphical representations against the data frame as interface. We created custom visualizations for bar and line charts and incorporated unique input methods, such as a slider for setting alarm thresholds, all realized through Jetpack Compose.

### Data visualization design

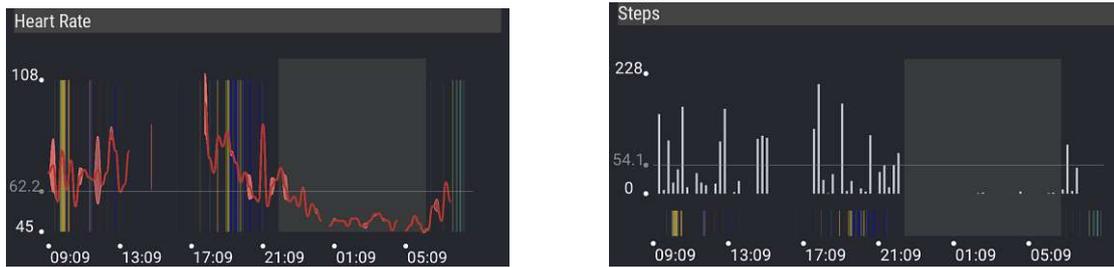
The phone application offers a range of visualizations focused on either usage or health data, providing insights into digital and physical well-being.

**Usage Data** : Derived from Android’s UsageStatsManager API, usage data informs several graphical displays within the app:

- **Daily Overview:** The main feature of the overview screen is a doughnut chart displaying application screen time and the number of phones unlocked since midnight, as illustrated in Figure 4.3a. This layout closely mirrors the design of the Digital Wellbeing dashboard.
- **Daily Overview Over Time:** Swiping the doughnut chart switches to a 24-hour clock-like graph with colored segments for app usage, helping identify heavy usage periods, as shown in Figure 4.3b.

<sup>15</sup>Rally Material Design, <https://m2.material.io/design/material-studies/rally.htm> and <https://github.com/android/compose-samples/tree/main/Rally-Accessed July 2023>

<sup>16</sup>Kotlin Dataframe, <https://github.com/Kotlin/dataframe-Accessed July 2023>



(a) Heart-rate data with phone usage and sleep data (in grey).

(b) Step data with phone usage and sleep data (in grey).

Figure 4.5: Health data visualizations for the last 24 hours.

- **App-Specific Overview:** Displays a 24-hour usage breakdown for a selected app, including alarm triggers as white marks and a list of timestamps, as shown in 4.3c. Beneath the clock display, a bar chart presents the weekly aggregate of screen time over recent weeks.
- **Historical Data Overview:** Offering a long-term usage perspective, another view presents weekly screen time totals as a bar chart.

**Health Data Visualizations** : Health data sourced from Google Fit includes the last 24 hours of activity:

- **Heart Rate:** Displayed in 5-minute intervals on a line graph, with app usage and sleep data integrated for a comprehensive health overview, as shown in Figure 4.5a.
- **Steps Data:** Step counts are aggregated into 5-minute intervals and displayed as a bar chart, with app usage shown on a separate axis, depicted in Figure 4.5b.
- **Sleep Data:** Sleep duration is shown in the heart rate and step charts as large grey blocks, indicating bed and wake times without detailing sleep cycles for simplicity and accuracy concerns.

### Watchful Watch Companion Application

**Technical design:** Similar to the phone app, the companion app for the watch was developed using *Kotlin* and Jetpack Compose. A backend app manages communication and data storage, utilizing protocol buffers for efficient data handling<sup>17</sup>. Additionally, distinct activities were crafted for alarm functionalities, illustrated in Figure 4.7c and to furnish detailed data visualizations. The watch face component, depicted in Figure 4.7a, is built on a *WatchFace Service*, displaying the current data from the storage layer.

<sup>17</sup>protobuf, <https://github.com/protocolbuffers/protobuf>—Accessed July 2023,

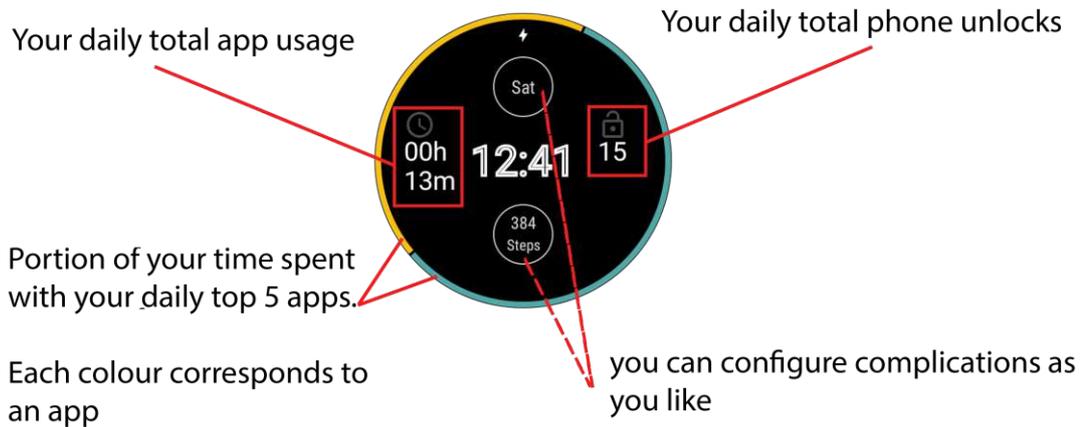


Figure 4.6: Explanation of the available fields of the *Watchful* watch face that was supplied to the participants.

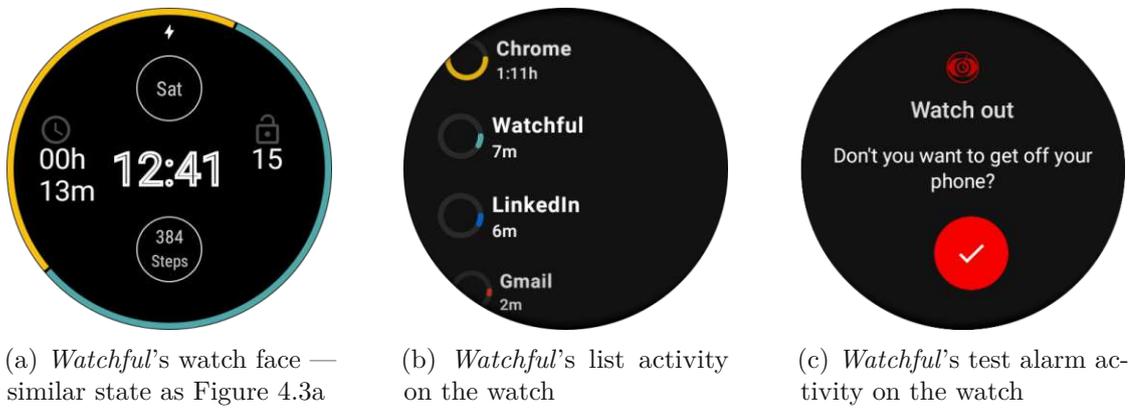


Figure 4.7: *Watchful's* watch application screens.

For a detailed breakdown of the watch face's displayed information, refer to Figure 4.6. Notifications on the watch are activated via the phone application once a usage limit is initially exceeded. If the participant persists in using the app beyond this point, an alarm is set off after a 10-second threshold period.

**User interface implementation:** The watch face features a doughnut chart showcasing the top five applications by screen time, along with a sixth 'other' category, mirroring the central design element of the phone app (refer to Figure 4.3a and 4.7a). To the left of the time display, the total daily screen time is shown in hours and minutes, while to the right, the cumulative count of phone unlocks is presented. Additionally, two complication slots above and below the time display offer customization options, potentially used to show information like the date, battery level, weather conditions, and more (as detailed in Figure 4.6). The watch app includes an additional activity beyond the watch face,

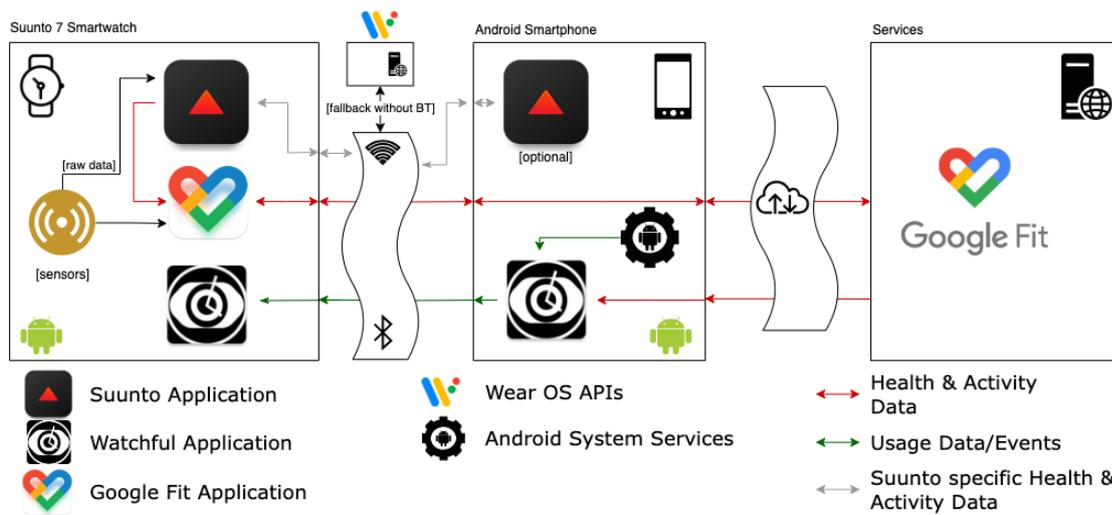


Figure 4.8: Data flow between all components.

designed to provide a more detailed view of data in a list format, which displays up to six items (the top 5 applications by screen time and an 'other' category), as seen in Figure 4.7b. Each item in the list displays the application's name, its daily screen time, and a doughnut chart indicating its share of the total daily screen time. The alarm screen, illustrated in Figure 4.7c, features a design highlighted by the color of the application that triggered the alarm, including both the app's logo and the OK button.

**Watchful's components communication:** Figure 4.8 illustrates how data is exchanged among the key components of the prototype's architecture. The diagram includes the WearOS data layer: the phone and wearable device communicate through Bluetooth. If Bluetooth is unavailable or turned off, the system automatically switches to using a Google Service via WiFi or LTE for data exchange<sup>18</sup>. Interactions between the phone and the watch app, rely on WearOS APIs, such as the data layer, to push latest usage figures or send notifications. To conserve bandwidth and battery life on both devices, the system is designed to transmit only essential updates. This means no data is sent if there's no new phone usage activity, minimizing unnecessary communication. The system ensures that application or health data remains on the device, only leaving if participants choose to export their data upon completion of the study.

### 4.2.3 Evaluation - User Study

To evaluate the prototype's impact, a preliminary user study was conducted, where quantitative data regarding phone usage was gathered. As shown in Table 4.1, the study

<sup>18</sup>WearOS data layer, <https://developer.android.com/training/wearables/data/data-layer>—Accessed July 2023

was divided into three phases. Participant interviews offered a deeper understanding of their individual experiences.

### Study Design

Nine students (2 females, 7 males) were recruited from a pool of bachelor course participants using word of mouth. Selection criteria included their willingness to undergo digital detox and ownership of an Android smartphone. Participating students received bonus points as compensation. Those interested had to read an information sheet and sign a consent form before joining the study. Participants in the study were provided with smartwatches and guided through the setup process during the briefing meeting, which always took place on Mondays. Instructions for the first week involved wearing the watch as much as possible, including during sleep, to acclimate to it and familiarize themselves with the watch face. The application observed their behavior during this time. At the end of the first week, participants received an email reminder to begin using the nudging functionality for selected applications during the second part of the study. The email also included a brief survey to gather initial impressions and address any technical difficulties or questions. Upon completion of the two-week study period, participants returned to the lab to submit their data and hardware exports and participate in interviews about their experiences. The interviews were audio-recorded using a handheld recorder.

Table 4.1: Study Phases Description.

Phase	Description
<b>Baseline Phase</b>	<ul style="list-style-type: none"> <li>• 7 days prior to the beginning of the study.</li> <li>• Extraction of screen-time only as a reference.</li> </ul>
<b>Passive Phase</b>	<ul style="list-style-type: none"> <li>• First 7 days.</li> <li>• Participants should accommodate themselves to the watch.</li> <li>• Only monitoring of screen-time through <i>Watchful</i> applications.</li> <li>• <b>No alarm intervention.</b></li> </ul>
<b>Active Phase</b>	<ul style="list-style-type: none"> <li>• Last 7 days.</li> <li>• Continuation of monitoring.</li> <li>• <b>Active alarm intervention.</b></li> </ul>

In contrast to previous studies [OSDE18b, PBS<sup>+</sup>23, PBH20b], the week preceding the study's commencement served as the baseline reference for comparing subsequent two-week periods of usage. Due to the limited number of watches, only three participants could participate simultaneously. This approach proved beneficial, particularly in the

initial phase, as it facilitated the streamlining of briefing and setup procedures and enabled prompt resolution of technical issues. For instance, certain Android distributions' manufacturer-specific characteristics necessitated consideration to prevent system processes or unique UI widgets from skewing usage statistics and disrupting user experiences. Software patches could swiftly be developed and disseminated to participants via Android's Play Store to address minor issues.

### Measurement

Using the participant's phone usage history, the following metrics were extracted to assess behavior throughout the study period and at least seven days before its commencement:

- Start and end timestamps of applications running in the foreground.
- Timestamps of phone unlock events.
- Timestamps and application origin of alarm events.
- Timestamps, application, and nature of alarm-settings changes (e.g., creation, deletion, or update of limits).

Additionally, with the integration of *Google's* Google Fit<sup>19</sup> into the watch, additional physical metrics were accessible for use in phone-application visualizations and post-study analysis:

- Heart rate (time series data).
- Steps (time series data).
- Sleep activities (beginning, end, and sleep cycle).

Participants were instructed to export their data at the study's conclusion using a feature integrated into the phone application. This application collects data from a local database, while remote Google Fit services generate domain-specific CSV files labeled with a UUID on the phone's internal storage. Finally, to facilitate sharing through a participant-selected channel, a zip archive was created as a final step. An import routine was utilized to transfer the zip-archived files into a dedicated timescaleDB<sup>20</sup> database, which was running locally on the moderator's notebook. This database served as a centralized repository for all the study's data. Leveraging the powerful tools provided by TimescaleDB for interacting with time series data, event data describing ongoing user interaction with the application in the foreground was converted from a descriptive representation into time-series data points with one-minute resolution. As depicted in

<sup>19</sup>Google Fit, <https://www.google.com/fit/>—Accessed May 2023

<sup>20</sup>TimescaleDB, <https://www.timescale.com/>—Accessed May 2023

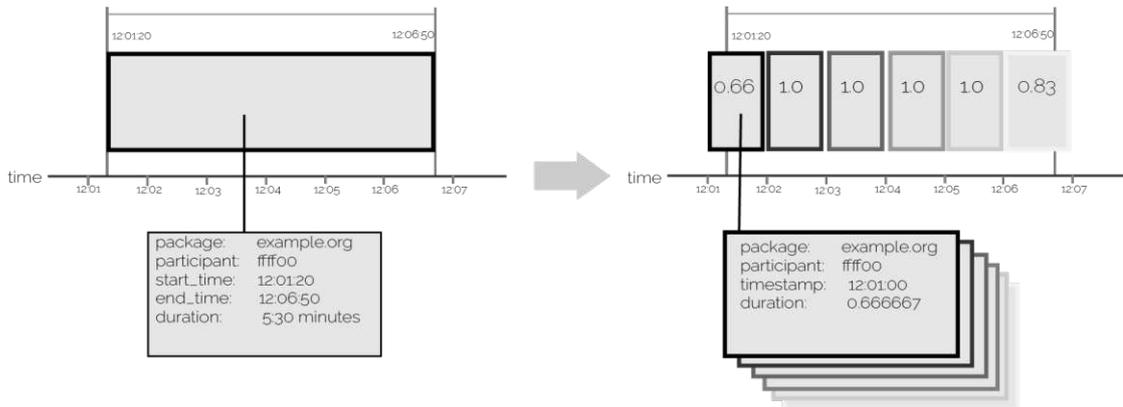


Figure 4.9: Transforming descriptive event data to data points for easier analysis.

Figure 4.9, this transformation resulted in six data points for each event, each with a duration value that represents a fraction of the event’s duration at the given timestamp of the full minute. Consequently, the process of preparing data for statistical analysis for arbitrary time frames and buckets, with optional gap-filling functionality, was simplified through this transformation. To conduct an initial exploration of the data, which had been consolidated into a unified database, the visualization tool *Grafana*<sup>21</sup> was employed. Custom views were implemented through dashboards, facilitating insightful analysis.

#### 4.2.4 Results

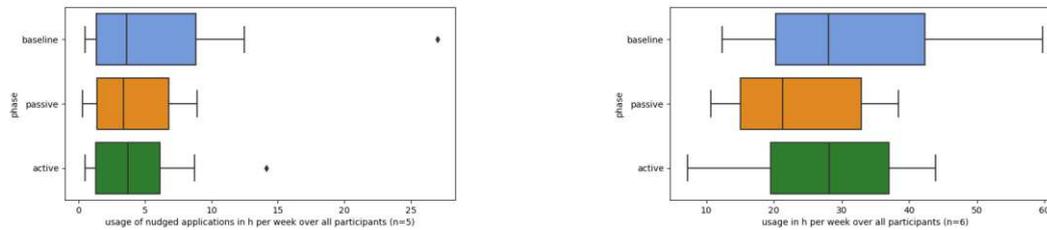
Data from 3 of the original 9 participants were excluded due to incomplete and erroneous records, resulting in a remaining group comprised of 5 males and 1 female, with an average age of 23.5 years and standard deviation = 1.70. It should be noted that for metrics related to the physical attributes of participants (such as sleep patterns), baseline data preceding the study commencement was not available. Consequently, any conclusions regarding the impact of the interventions on these physical attributes are outside the scope of the presented user study.

#### Impact of the intervention on phone usage

To test for significant changes between baseline and passive/active intervention phases, a Wilcoxon signed-rank test was used due to the small sample size. The key findings from the study on the impact of intervention methods on screen time and app usage include the following key points:

1. **Screen Time Reduction:** There was a notable decrease in overall screen time during the first week of the study, which was statistically significant ( $p = 0.03125$ , effect size  $e = 0.572$ ). However, this reduction was less pronounced during the

<sup>21</sup>Grafana Labs, <https://grafana.com/grafana/>—Accessed November 2023



(a) Weekly app usage with limits by phases.

(b) Weekly overall phone usage by phases.

Figure 4.10: Analysis of weekly usage and changes for both overall and application-specific screen time.

active week, where intervention methods were fully implemented ( $p = 0.15625$ ), as shown in Figure 4.10.

2. **App Usage with Defined Limits:** For apps that had usage limits set, there was a consistent decrease in usage across both passive and active weeks. During the passive week, usage dropped by 17% ( $p = 0.028839$ , effect size  $e = 0.3965$ ), and during the active week, it decreased by 6% ( $p = 0.1489$ ).
3. **Changes in "Problematic"<sup>22</sup> App Usage Patterns:**
  - a) A reduction in usage of "problematic" applications was observed between 19:00 and 07:00 during both passive and active phases, approximately -5% ( $p = 0.00049$ ,  $e = 0.33$ ).
  - b) Conversely, there was an increase in overall usage of these apps during the day (between 07:00 and 19:00) in the active phase.
4. **Effectiveness of Alarms:** Alarms introduced as part of the intervention did not perform as reliably as expected. The presence of alarms might have nonetheless contributed to the continued reduction in the usage of apps with limits between 19:00 and 07:00. The selection of the time window for daily limits could have been more optimal.

### Findings from survey and interview data

After the first week, participants completed a survey to share initial impressions and feedback, the survey hinted at user experience trends. However, more in-depth insights emerged from semi-structured interviews, with questions emphasizing personal experiences with the prototype's features, the perceived reduction of screen time, likes and dislikes, and suggestions for future development. Analysis of these interviews, facilitated by a Miro dashboard, and performed by two researchers, identified the following key findings:

<sup>22</sup>Among the top 5 apps renowned for their "endless scrolling" and binge-use tendencies, with enabled alarm limits.

- 1. Watch Interface and User Experience:** The watch interface received favorable feedback from participants, although some found wearing the watch to be cumbersome. As Participant 2 described *I used my phone a lot more before that.[...] I wasn't used to wearing a watch. And so it was kind of like you have something that always reminds you why you're wearing this [watch] [...] I don't really like the watch, as my wrists are too small for the watch.* Participant 4 said *[...] Maybe just like being shown how much you use your phone on a daily basis, which the watch facilitates— you're consciously thinking about it. But after a while, it just gets thrown into your subconscious again. So you don't really think about it [=your usage] [any longer].*
- 2. Alarm Feature Feedback:** Although expressing annoyance with the alarm's vibration feature, participants provided overall positive feedback. Participant 1 shared *I limited my notifications to the watch just because it gets annoying, especially if you're in huge group chats or something. It vibrates all the time, which is really off-putting. [...] But you can customize it [=the notifications]. So that's fine.* Participant 6 said *Most useful was the vibration on the watch when I overused too much. Because it was really, you know, it made me kind of angry with the watch. But that was the point. [...] every time it vibrated, I didn't want it to repeat, so I didn't even use the app at all. So I just forgot about it. Yeah. So I think that's a good sign.*
- 3. Reduced Phone Interactions:** Participants observed that the watch potentially decreased their phone interactions by enabling them to read notifications directly on the watch [*This finding contributes to Chapter 7, subsection 7.3: User Autonomy and Control.*] Participant 1 said *I would say that people tend to unlock their phone less if they have a watch just because you get notifications and you can check the time using the watch. Like I think most people they use, they're — even if they just want to check the time or they're bored, they will look at their phone and then say, Oh, I got a new notification. Then they unlock it. So, especially with certain apps that like get push notifications, they give push notifications, so you do engage. So yeah, I think the watch can curb that if that's what you want to do.*
- 4. Health Data Integration and Sleep Tracking:** While the integration of health and usage data was met with skepticism, the sleep-tracking capabilities of the watch were well-received. Participant 3 mentioned *I like, for example, that I could see how my heart rate changed during the usage of an app. So I could see the excitement that caused the item — the appeal of the app to use it, for example. And I also like that I could see my overall health a bit better. So I like to know when I'm stressed or how I could sleep, for example. [...] I think that I've improved my sleep a bit using this app or the watch overall.* Participant 5 said *I think — the most used features where the heart rate sensor and the sleep tracker [on the watch through the Suunto app]. Because it was like, okay. And now we have a goal to live up to.*

5. **Enhancing Alarms for Better Accountability:** There is a need to enhance the alarms with greater transparency and accountability. For instance, Participant 4 said *Like, if you set up a threshold for an app. I don't know if you could, like, maybe color code how far away you are from that threshold.* Participant 6 explained *Like, I want to use the phone for 3 hours a day, and that's it and maybe you just get every hour [a] notification: You've used it for one hour — for 2 hours — as it gets closer to the 3 hours [limit].*
6. **Structured Guidance and Goal Setting:** A desire for more structured guidance and recognition was expressed by participants, indicating a need for improvement in support. Participant 3 said *Something like an app-specific graph. Like, if you want to use, for example, Facebook a bit less than it would be useful if the app had some summary of only the usage of, for example, Facebook. And then you could set some goals for the week or so maybe or get some notifications that you did better this week and use it less or something like that.* Participant 4 mentioned *You could do something like where you see the — where you put in pre-configured alarms for the most used apps of that person. So the first week, you analyse usage using the watch, and the second [week], you say, "Okay, these are your top three apps. Would you like to set up an alarm for these apps"?*

#### 4.2.5 Discussion

Reducing screen time on phones and specific apps proved effective for most participants. The study heightened participants' awareness regarding their app usage patterns. Equipped with the prototype application and the smartwatch, they gained easy access to their usage statistics. This visibility enabled them to make more informed choices about their smartphone interactions, fostering a more mindful approach to app usage. For some participants, wearing a smartwatch was a new experience, acting as a constant reminder of their participation in the study and its objectives. Although this novelty effect tended to diminish over time, in some instances, had a more substantial impact on reducing app usage than initially expected. This was particularly true for those who found the watch's size and weight to be intrusive. We observed instances where nudged applications had set limits that were either close to or beneath the users' average daily usage from previous weeks. In these cases, the alarm feature effectively curtailed the usage of certain apps beyond their preset limits, presumably aiding in the reduction of overall daily screen time for these selected apps. Drawing parallels to the alarm design used by Okeke et al. (2018), we infer that the alarm mechanism in our proposed design might not facilitate the development of lasting, sustainable habits over time [OSDE18b]. In many instances, participants nearly unanimously characterized the alarms as exceedingly irritating and overly aggressive. One participant even went so far as to say that the initial shock of the alarm was so jarring, that they made it their mission to avoid triggering it for the duration of the study. This reaction was not the desired outcome of implementing alarm nudges. Nevertheless, such responses offer valuable insights, highlighting the importance of careful nudge design, as advocated in the concept of "nudge for good" [Tha18]. This

behavior is anticipated to be a short-lived reaction, possibly resulting in the eventual discontinuation of the use of such interventions. This aligns with findings from Okeke et al. (2018) [OSDE18b], who noted similar challenges regarding the long-term efficacy and sustainability of their interventions. The smartwatch, by offering timekeeping and notification forwarding features, potentially reduced the frequency of phone interactions for its wearers. By centralizing access to time and notifications, the watch could diminish the temptation to 'wander off' into other phone applications, thus lowering the likelihood of prolonged screen engagement. This concept echoes findings by Oulasvirta et al. (2012), who suggested that the habit of checking one's phone can often lead to unintended usage of additional apps, thereby increasing overall screen time [ORMR12]. However, the cognitive load associated with receiving notifications on a smartwatch might not be significantly less than that of notifications appearing on a smartphone. This similarity in "attention cost" between device notifications [SMY15, MPV<sup>+</sup>16, MBL<sup>+</sup>17] indicates that the selection of which applications are allowed to push notifications to the watch should be made with careful consideration, aiming to balance convenience and potential distractions. The observed reduction in screen time cannot be attributed entirely to the smartwatch app. The mere presence of the smartwatch was found to be sufficient to prompt and remind participants to engage in a detoxification process. The evidence suggests that interventions targeting not only smartphones but also the wider ecosystem, including wearable devices such as smartwatches, have a significant impact on phone usage and result in a notable reduction in screen time. Also, external factors, such as increased workloads, social engagements, or travel, could beneficially influence screen time reduction by naturally limiting free time or altering daily routines. With all participants being students experiencing the busy end of the semester, their phone usage might have been affected. Although these potential influences weren't reported as significant or memorable by the participants during the interview and debriefing, they could have nonetheless played a role in changing their screen time behaviors.

Changing ingrained habits requires time and patience, often more than three months, for sustainable results, with setbacks and motivation lapses being part of the process [LVJPW10]. Given this, the short-term nature of a two-week intervention is unlikely to yield lasting changes in phone usage habits, with initial reductions in usage typically not sustained over time. This was observed during the study, where usage decreased more significantly in the first week than in the second, indicating a possible decline in commitment to reducing screen time. Participant behaviors, such as disabling features critical for intervention effectiveness, with Participant 2, who disabled Bluetooth during the second week of the study, effectively killing alarm and watch-face data updates, highlight the challenges of maintaining reduced usage. Additionally, the discomfort reported by some participants wearing the prototype watch suggests that while it served as a reminder of their goals, the novelty and its effectiveness faded over time, leading to a probable return to undesired behaviors. This aligns with other studies questioning the long-term viability of digital detox interventions and the observation that even with access to digital well-being tools, many users remain only casually engaged, finding the data interesting but not motivating enough to spur behavioral change [HHKK16,

OSDE18b, KJKL19, MRDR19]. During the study's active phase, participants were asked to set limits on apps they found problematic. One participant didn't set limits, leading to a decrease in overall screen time without significant changes in usage of the most-used apps. The prototype's design unintentionally kept the alarm feature inactive until the second week, a decision that, in retrospect, might have provided clearer insights if implemented differently. Some participants set their usage limits higher than their average, aiming to prevent binge usage rather than consistently reducing screen time. Automating limit settings based on past usage or guiding participants to set more realistic limits could enhance the effectiveness of usage reduction. However, the initial week didn't significantly improve usage awareness, preventing participants from setting impactful limits. Altering alarm settings due to annoyance led to less stringent limits, suggesting that allowing participants to set and adjust their own limits may reduce the alarm feature's effectiveness. Contrarily, fixed limits based on past usage, as seen in other studies [OSDE18b, SMWM22], could more clearly demonstrate intervention efficacy. Yet, overly strict limits risk intervention abandonment [KJKL19, HHKK16]. Lyngs et al. (2019) highlighted the infrequent implementation of expectancy components in digital interventions, pointing out the potential of exploring user confidence in reaching goals [LLS<sup>+</sup>19].

The sleep data from the study indicates most participants go to bed well past midnight. The prototype's definition of a "daily" timeframe as 00:00:00 to 23:59:59 may have led to discrepancies in app usage tracking, where resetting the app screen time at midnight allowed for usage without triggering alarms. This setup potentially reduced the timing effectiveness of alarms but not necessarily their overall effectiveness since usage was tracked. This scenario mirrors findings by Kim et al. (2019), where users would wait for usage restrictions to reset at midnight to continue app use [KJKL19]. Considering the importance of reducing screen time before sleep [MHZ<sup>+</sup>19], it's noteworthy that app usage deemed alarm-worthy tended to spike between 22:00 and 01:00. In hindsight, resetting usage limits right before bedtime was counterproductive. This situation highlights the need for the application's concept of "daily" to align with the users' perceptions and lifestyles, ensuring that interventions like alarms are effective and timely.

### Summary and recommendations

Addressing RQ 1, the alarms did not maintain the initial week's reduction in screen time for various reasons, including their possibly overly forceful nature. Yet, participants found them helpful for cutting down on specific apps, indicating a positive but not generalizable impact due to the study's small scale and brief duration. Future designs might benefit from incorporating positive reinforcements and more refined nudging strategies to effectively encourage screen time modification. The watch face's real-time feedback on phone usage was well-received, providing an easier and more accessible way to monitor screen time than using phone apps or settings. The physical presence of the watch served as a constant reminder to limit phone use, although its novelty and impact faded over time. The notification relay feature of the smartwatch, as noted by

one participant, suggested the potential for reducing phone interactions, echoing Pizza et al. (2016) discussions on smartwatches' roles in managing phone use [PBML16]. Overall, for RQ 1, smartwatches show promise in supporting digital detox efforts, yet the study only revealed limited short-term effects on screen time reduction. Regarding health data RQ 2, only sleep data provided usable insights, indicating a negative correlation between phone use and sleep quality. The inability to analyze heart rate and step data due to incompleteness accentuates the need for more robust data collection methods in future studies. Finally, answering RQ 3 requires reflecting on the intervention design and prototype issues. Participants' suggestions for improvements, such as alarm snoozing and greater transparency, highlight areas for enhancing user experience and intervention effectiveness. Adapting interventions based on goal-setting literature and user feedback could lead to more effective digital detox strategies.

### 4.2.6 Conclusion

This research introduces a novel method aimed at aiding individuals in their digital detox efforts, leveraging a smartwatch-smartphone ecosystem to implement an intervention based on negative reinforcements. Even though the the growing interest in digital well-being, the utilization of wearable companion technology in facilitating digital detox remains relatively unexplored both in academic literature and practical applications. The designed system features a mobile app that monitors and reports phone usage data, enabling users to set daily screen time limits for specific apps. Exceeding these limits triggers a vibration alert on the connected smartwatch, encouraging users to reduce their usage of the particular app. The system also integrates with Google Fit to provide a comprehensive view of the user's physical health metrics alongside their device usage data, offering a holistic approach to managing screen time and well-being. A preliminary study involving six participants provided insights into the effectiveness of this approach, revealing a significant reduction in screen time during the initial week of usage. However, the efficacy of the alarm feature in the second week was inconclusive, with participants either setting lenient limits or adjusting them to avoid triggering alarms, suggesting difficulties in establishing realistic self-regulation goals or resistance to the intervention's intrusiveness. Smartwatches exhibit potential as tools for enhancing digital detox initiatives, as evidenced by participants' increased awareness of their screen habits and a reduction in phone interactions, facilitated by the watch face's easy access to usage stats and health data. Yet, the study's limitations, including its brief duration and small sample size, temper the conclusiveness of these findings. Participants' mixed feedback about the alarm's effectiveness and their appreciation for the watch face's simplicity indicate areas for further development, emphasizing the need for a more user-friendly and adaptive intervention design. Future directions should explore the integration of smartwatches with emerging health data standards like *Health Connect*<sup>23</sup>, expanding compatibility and potentially increasing user adoption.

---

<sup>23</sup>Google Health Connect, <https://developer.android.com/guide/health-and-fitness/health-connect> – Accessed August 2023

Additionally, adopting a more nuanced approach to tracking and intervening in phone usage—possibly through innovative metrics and personalized feedback—could enhance the efficacy and user acceptance of digital detox solutions. A key area for further research is the psychological impact of reducing screen time. Future research should aim to provide a more comprehensive assessment of the psychological indicators of well-being, encompassing positive and negative affect, anxiety, and other measures of psychological well-being. This focus is essential in order to determine the efficacy of reducing screen time and its ultimate utility in enhancing overall mental health, thereby addressing whether such reductions are genuinely beneficial in the long term.

**Limitation:** The study has a few constraints that impact the scope of its findings. The small number of participants and technical issues could have influenced the limited data collected. The study's short duration of two weeks likely captured only the immediate effects of the intervention, with the intensive alarm feature possibly leading to longer-term disengagement. The metrics used, screen unlock frequency, session duration, and usage trends over time, were selected as common proxies for smartphone engagement in digital well-being research. We recognize, however, that such metrics are subject to a variety of influencing factors (e.g., work context, notification load) and may not always be reflective of intentional overuse. Rather than labeling behaviors as "good" or "bad," we focused on visualizing trends and allowing users to contextualize patterns for themselves to mitigate misinterpretation. The intervention design, while adaptable to a smartwatch interface, deviates from established best practices and lacks personalized feedback, suggesting room for improvement. Participant diversity is limited, as all are university students from similar backgrounds. Additionally, the user interface's reliance on color coding poses accessibility issues for individuals with color vision deficiencies, indicating a need for more inclusive.



# Part III

## Reactive Companions



# Informational Companion

This chapter examines the design and evaluation of reactive informational companion.

## 5.1 MapGPT Companion

This chapter is based on our following publication:

### Publication

Shahu, A., Cipot, P., Asteriou, P., Wintersberger, P., & Michahelles, F. (2025, May). Integrating AI Assistants to Advance GIS Application Usability. In Proceedings of the 16th Biannual Conference of the Italian SIGCHI Chapter (CHIItaly 2025), (Submitted - Under Review).

Maps have been indispensable to human civilization for centuries, originating around 2300 BCE with the Babylonians. They have consistently served their fundamental role of depicting locations and routes [Fue24]. The advent of computer technology post-World War II heralded the first digital mapping system in 1962, developed by Roger Tomlinson [FS11]. Today, map-based applications are an integral part of the digital world. These applications facilitate interaction with geographic data on digital platforms, proving essential for routine navigation and specialized tasks such as data visualization, analysis, and manipulation [RFB20]. Map-based applications are integrated into interactive exhibits, affording visitors the opportunity to explore historical maps and gain insight into geographic and cultural changes over time. For outdoor recreational activities, such as hiking or tourism, these systems enhance navigational aids by allowing users to interact with maps, obtain directions, inquire about nearby attractions, or gain historical context about the areas they are visiting without having to stop and manually search through a traditional map.

Geographic data is ‘information concerning phenomena implicitly or explicitly associated with a location relative to the Earth’ according to the International Organization for Standardization, e.g., the coordinates of a city or the route of a road [ISO14]. These functionalities are grounded in Geographic Information Systems (GIS), which vary from common tools like Google Maps to specialized platforms like ViennaGIS. ViennaGIS provides users with comprehensive information across approximately 50 datasets covering a range of sectors including transport, culture, leisure, public facilities, education, health and social affairs, and environmental concerns [Cit95]. This information is displayed to users via a Graphical User Interface (GUI), which also enables them to query and manipulate the data. User input typically occurs through devices such as keyboards or mouse on personal computers, whereas for mobile devices, it often involves touch. As applications become more complex, their GUIs often sacrifice valuable map space for additional features like toolbars and query tools. This reduction in map visibility contradicts user preferences for larger map areas, as evidenced by a study done by Haklay and Zafiri (2008) where participants consistently maximized the map display when possible [HZ08]. Prior research has demonstrated that the absence or excessive complexity of search tools, combined with poor usability of map or GUI elements, significantly compromises the overall usability of map-based applications [KJH10, MMKM17]. This is particularly problematic for novice users, who may be discouraged from using these systems altogether [LDV11]. The mental models of novice and proficient technology users can vary significantly, encompassing their understanding of a system’s function, behavior, structure, and predictable responses. However, neither expert nor novice users, nor even the developers, possess a complete mental model, as they likely have not experienced the entire system and are often unaware of their own assumptions and understanding [Hea91, Wae90].

Over the past few years, the growing availability of Large Language Models (LLMs) has provided valuable assistance to novice users in the creation of logical expressions. LLMs can interpret natural language and convert it into logical queries, a process defined by the Environmental Systems Research Institute (ESRI) as ‘*the process of using mathematical expressions to select features from a geographic layer based on their attributes*’. For example, users can enter a command such as "Select all road segments named Green Apple Run" in natural language. This is typically easier for novices than learning to use complex query tools that they may only need occasionally. OpenAI’s ChatGPT, which also provides a platform for building customized AI assistants, is an example of such an LLM. At the moment, there are no established design guidelines for interactive assistants based on maps. The contributions of this work are multifaceted and important in advancing the integration of AI technologies within GIS. Firstly, this chapter introduces MapGPT companion, an innovative AI-driven map assistant that leverages LLMs to facilitate natural language interactions, as depicted in Figure 5.5. Secondly, it establishes basic recommendations for the future development of map-based AI assistants, drawing on empirical data and insights gained through a comprehensive user study. The study also represents a third significant contribution, providing robust user experience data that demonstrates the practical benefits and challenges of integrating AI into GIS interfaces.

### 5.1.1 Background

Krahnstoeber et al. (2002) developed a real-time framework for natural multi-modal interaction with large-screen displays, utilizing a combination of audio and visual inputs to enable users to interact using gestures and speech while receiving immediate responses [KKYS02]. Their prototype system included a directional microphone and a single active camera, employing face and palm detection, head and hand tracking, and continuous gesture recognition, alongside speech recognition and feedback generation, all with moderate computational demands. Building on this, Rauschert et al. (2003) introduced the Dialogue-Assisted Visual Environment for Geoinformation (DAVE\_G), a new GIS interface designed to streamline complex GUIs in GIS applications by leveraging multi-modal interaction, domain knowledge, and task context [RSF<sup>+</sup>03]. DAVE\_G featured a large screen, non-intrusive microphone domes, and active cameras, supporting speech and gestures as input. While the prototype demonstrated basic functionalities and potential for expansion, its adoption for widespread internet use is challenged by the requirement for gesture control, which necessitates device-specific initialization not suited for broad implementation or casual user setups. The MATCHKiosk, a multi-modal interactive city guide, was tested in Washington, D.C., allowing inputs via speech, handwriting, and touch [JB04]. Its responses included text and synthetic speech. The GUI featured a dynamic map, metro and restaurant search buttons, and a 'virtual agent'. Although closely aligned with the MapGPT vision, MATCHKiosk is limited to specific commands like 'route' and the GUI elements consume much of the screen, leaving limited space for the map.

At the time of writing this dissertation, there are only a few studies on the integration of AI and GIS. Li and Ning (2023) developed LLM-Geo, an autonomous GIS prototype designed to enhance GIS accessibility and user-friendliness by being self-generating, self-organizing, self-verifying, self-executing, and self-growing [LN23]. Unlike text-based assistants like GitHub Copilot X, LLM-Geo processes spatial data to produce visual outputs such as maps and charts. Zhang et al. (2023) developed GeoGPT, designed to accept natural language descriptions from non-professionals and translate them into various geospatial operations, including data collection, processing, and analysis [ZWW<sup>+</sup>23]. This prototype employed the OpenAI GPT-3.5-Turbo API and yielded satisfactory results. Despite these advances, a significant challenge remains in bridging professional and general knowledge within LLMs. A 2018 study by Kim et al. (2018) highlighted user distrust in speech recognition for banking chatbots on phones, with a preference expressed for two-way voice interaction over one-way voice input [KGJ18]. It indicated that voice input alone does not enhance chatbot acceptance. Thus, a new map-based AI assistant should incorporate voice-to-voice communication to improve user engagement. In the article 'Annals of GIS,' Zhu et al. (2021) argued that future generations of GIS must prioritize simplicity [ZZLQ21]. They defined this as creating systems that are "easy to use" — focusing on user goals rather than complex procedures—and "easy to compute" by leveraging high-performance computing infrastructure. This approach, they suggest, would enhance the user experience for both novice and experienced users. Previous work demonstrates

a notable evolution towards more intuitive and user-centric GIS interfaces, evidenced by the emergence of newer developments such as LLM-Geo and GeoGPT, which leverage LLMs to enhance accessibility and functionality.

### 5.1.2 MapGPT companion design

We introduce MapGPT, a novel AI-driven map assistant. It leverages LLMs to interpret and execute user commands in natural language. MapGPT is designed to simplify complex GIS interfaces by translating user utterances into predefined query functions, thereby eliminating the need for users to master complex search tools or manually construct logical queries.

#### System Design Rationale

The MapGPT interface comprised of a text field for input, buttons for sending messages and enabling voice input, a display area for chat history, and indicators for connection and query status. The MapGPT section was designed to be collapsible, thereby allowing users to expand the map view. Furthermore, the capacity to initiate voice input through a designated wake word was available, thus facilitating interaction even when the MapGPT interface is minimized. Previous systems, such as QuickSet, utilized a tablet with touch input [JCM<sup>+</sup>97], DAVE\_G incorporated a webcam and microphone [RSF<sup>+</sup>03], and MATCHKiosk operated as a standalone system [JB04], which collectively highlight the diversity in user interface technologies. The QuickSet system demonstrated the effective use of voice input, while the MATCHKiosk system demonstrated excellence in speech output. Research by Kim et al. (2018) highlighted a user preference for voice-to-voice communication, which reinforces the value of incorporating these features into MapGPT [KGJ18]. Therefore, MapGPT has been designed to support both audio input and output functionalities. The voice output consisted of synthesized natural speech generated from the text output of the LLMs. Furthermore, in order to accommodate the diverse needs of users and technical constraints, MapGPT also provided the option of manual text input and output as alternative interaction methods, which serve to complement the voice functionalities.

The objective of MapGPT was to render graphical search tools obsolete by translating user utterances into predefined query functions, a strategy similar to that employed by GeoGPT [ZWW<sup>+</sup>23]. By employing LLMs to parameterize these natural sentences into specific query function attributes, MapGPT enabled users to interact through everyday language, thereby eliminating the need to master complex search interfaces or manually construct logical queries. In instances where MapGPT was unable to directly map an utterance to an established query function, the system was designed to request additional information from the user, thereby ensuring clarity and accuracy in the query response process. It is of paramount importance to provide meaningful feedback during the execution of user queries and when modifying the current view, as this is a fundamental aspect of enabling users to comprehend the activities of MapGPT. The implementation of asynchronous communication between the server and the client enabled the transmission

of query status updates while the server was still processing the query. This approach provided users with reassurance that their request was being handled, rather than leaving them to interpret a mere loading circle or progress bar. The underlying rationale for this decision was that such levels of transparency would enable the users to comprehend the consequences of their queries and to interact with the system in a more informed manner.

**Domain Knowledge Integration:** To integrate domain-specific knowledge, the LLM utilized by MapGPT was connected to the database of the GIS application. This linkage enabled the LLMs to access and utilize real-time data for query responses and explanations. Moreover, these language models permitted the configuration of an initial system prompt, which could define and clarify any domain-specific vocabulary that might have been ambiguous to the model. This feature was particularly useful for explaining concepts and terms that were not stored in the database, such as details about the GIS application itself that MapGPT supported. The incorporation of conversation history by MapGPT facilitated the generation of a more natural communication flow with users. This ensured that interactions with the system were perceived as a dialogue rather than isolated exchanges. It was important to maintain the context of the conversation, specifically to recall previous interactions within a session. It was recommended that each client visiting the application initiate a new session, allowing MapGPT to track and recall the dialogue history during that session. Some LLM interfaces, such as OpenAI’s Assistants API, are capable of automatically managing session contexts.

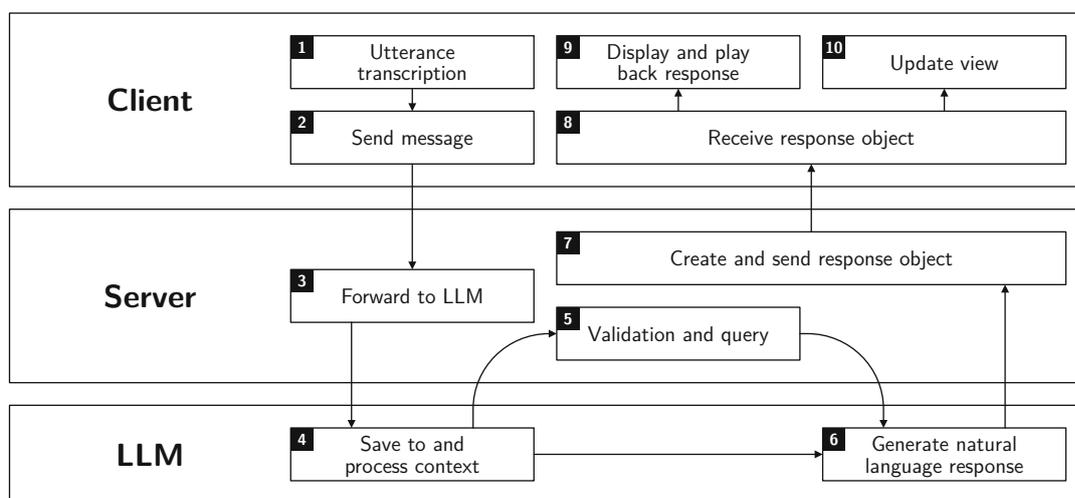


Figure 5.1: General data architecture of MapGPT.

**General Data Architecture:** As depicted in 5.1, upon launching the GIS application, the client establishes a connection with the server, which is already equipped with query functions that the LLMs can leverage. In instances where the user elects not to enter a query, the client converts the spoken input into a text string (1) and transmits this

string to the server (2). Subsequently, the server transmits the text to the LLM (3), where it is integrated into the existing context and processed (4). In the event that the LLM is unable to translate the message directly into a predefined query function due to the query being ambiguous, out of scope, or lacking specific parameters, it generates a response in natural language, both as text and audio. Upon successful mapping of the query to specific function parameters, these are forwarded to the server for validation and execution (5). Subsequently, the LLM utilizes the output from these functions to generate a response in natural language, which is further enhanced with pertinent domain knowledge. The response, in both text and audio formats, is then transmitted back to the server, where it is combined with the outputs from the executed functions (view parameters) and subsequently transmitted to the client. Upon receipt of the combined response object (8), the client displays the textual response and plays the audio (9). Concurrently, the graphical view is updated in accordance with the specified parameters (10).

### Implementation

The latest iteration of Zeitlinie Vienna<sup>1</sup>, an interactive web GIS that chronicles the history of tram networks in Vienna and Graz, Austria, serves as the foundation for the MapGPT prototype. The database for this application comprises the following:

- **Network Graph:** Consists of vertices and edges, where:
  - **Vertices** represent switches or termini.
  - **Edges** represent the tracks between vertices. These edges are equipped with attributes such as:
    - \* Operator details
    - \* Propulsion system details
    - \* Start and end dates
- **Paths:** Formed by multiple edges that combine to represent a specific tram route, with attributes including:
  - Line name
  - Destinations
  - Operating hours
  - Details on return routes and bi-directionality

Users can interact with the system by selecting a specific date, ranging from the tram network's inception in 1865 to the present, and can observe the network's evolution in annual increments or explore specific tram lines. The server for this application is

---

<sup>1</sup>[www.zeitlinie.at](http://www.zeitlinie.at) – Accessed Dec 2024

hosted on an Ubuntu 22.04 system. The backbone of the system is Django, a Python-based web framework known for its integrated object-relationship mapper. Django was the framework of choice due to its pre-existing use in Zeitlinie’s backend, facilitating easy extension. Zeitlinie’s data management also incorporates PostgreSQL with the PostGIS extension, supporting enhanced spatial data storage and functions [DW02, OH21]. Angular, a front-end web application design framework, is used to create a responsive user interface, benefiting from easy integration with MapGPT [Wil18]. To manage geocoding functionalities internally and avoid the constraints and costs associated with external services, a dedicated Pelias geocoding service was installed on the server [Pel16]. The asynchronous nature of user interactions led to the adoption of WebSocket technology for real-time, two-way communication between the client and the MapGPT service on the server, without requiring multiple HTTP connections [MF11]. For the AI components, OpenAI’s specialized Assistants API was selected for crafting custom AI assistants using its GPT models, along with text-to-speech technologies to generate natural-sounding audio responses. Finally, the system utilizes native browser interfaces—specifically, the Web Audio API and the Web Speech API—for audio playback and voice input transcription, ensuring data privacy by not outsourcing these functions to third parties [AC21, NSJ20].

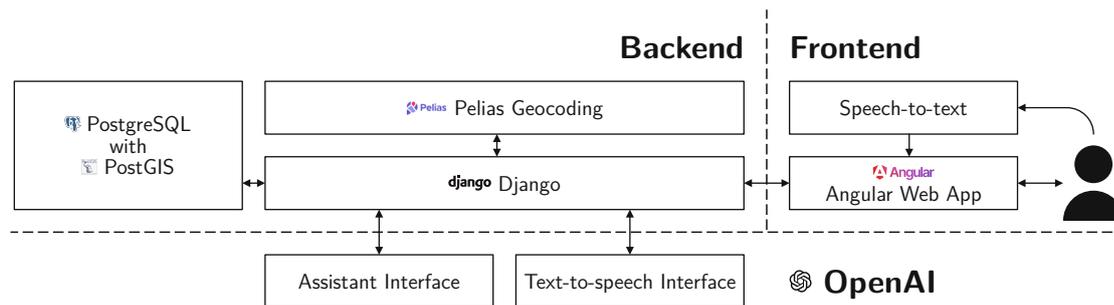


Figure 5.2: MapGPT software architecture]Software architecture of MapGPT and its GIS.

**Architecture:** The software architecture of the prototype (refer to Figure 5.2) integrates multiple components to facilitate interaction across various systems. At the core of this integration is the Django application, which serves as the primary hub for processing all incoming requests, including database queries, geocoding queries, and interactions with the AI assistant. User interaction with the system is managed through an Angular-based frontend web application, which supports both traditional and speech-to-text input methods. User queries are transmitted to the Django application via a WebSocket connection, where they are initially directed to the AI assistant. The assistant then processes these inputs, either parameterizing them to generate a function call or forming a natural language response directly if the query cannot be parameterized. When a function call is generated by the assistant, it is executed by the Django application, and the results are returned to the assistant. Subsequently, the assistant crafts a natural language

response based on the function's output. This response is then converted into speech using a text-to-speech API, producing natural-sounding audio. The final step involves the Django application, which aggregates the function output, the textual response from the assistant, and the URL of the generated audio into a comprehensive response object. This object is sent to the frontend, which then adjusts the map according to the specified parameters, incorporates the assistant's response into the chat history, and plays the audio feedback.

**AI Interface:** The AI interface of MapGPT leverages the OpenAI Assistants API, which was introduced in early November 2023. This API facilitates the development of custom AI assistants using OpenAI's GPT LLMs, with MapGPT utilizing the GPT-4 model [OAA<sup>+</sup>24]. Custom assistants are configured by specifying a name, selecting the model, and outlining the instructions and function definitions necessary for interpreting user messages. A significant advancement in this API is its support for threading, enhancing the assistant's capability to maintain context continuity throughout each user session. Function definitions within the assistant framework enable it to generate precise function calls in response to user queries. These function calls can then interact with other APIs or databases to gather and process relevant data. Once the data retrieval and processing are complete, the assistant receives the output and constructs a natural language response that integrates the obtained data. This response mechanism ensures that users receive coherent and contextually relevant information, thereby enhancing the overall interactivity and utility of the MapGPT system. The OpenAI Assistants API provides five objects, of which the following four were used in the development of MapGPT.

### Assistant

An assistant uses one of OpenAI's LLM with specialized instructions and the possibility of calling tools (predefined functions).

### Thread

A thread is a list of all messages exchanged between a user and an assistant, functioning as a personalized session and preserving context.

### Message

A message can be created by a user or an assistant. Messages can also include files additionally to text, but this was not used for MapGPT.

### Run

A run forwards a thread to an assistant, which then performs tasks (e.g., parameterization, natural language answer generation) in the context of the thread's messages. The assistant appends new messages to the thread during this process.

**Response Object:** MapGPT uses a custom data structure for the forwarding of any data from the Django application in the backend to the frontend. The *audio* attribute

links to a URL where a speech file of the response message is stored. The *location* object includes a name identified by the geocoding service and a bounding box (*bbox*) to specify the zoom area on a map. The *playback* object contains start and end dates, along with a boolean indicating whether the animation should play indefinitely. An optional *date* attribute specifies a new date. The *line* object includes an identifier (*id*), a path attribute *id* for a specific route in time, and a boolean to determine whether to show a diverging return route, if applicable. The *message* is text added to the chat history unless the *status* attribute is true, in which case the text appears as a query status. Finally, the *status* boolean differentiates whether the response object is a regular query response (false) or a status update (true).

**Query Functions:** The scope of query capabilities within the MapGPT system was predefined. This preparatory work entailed an analysis of user experiences gathered from the Tramway Museum Graz, where the Zeitlinie Graz exhibition has been featured since 2018. The Zeitlinie Graz exhibition is designed to cater to both tram enthusiasts, who possess a deep understanding of the domain, and the general public, who may not be as familiar with tram systems. In order to enhance the system's utility, the most frequently posed queries during museum tours, which could potentially be addressed by the system, were identified. These questions were subsequently converted into specific query functions that MapGPT could process, thereby enabling it to respond with relevant parameters. This approach ensures that the AI system is aligned with the informational needs and curiosities of the users.

**Graphical User Interface:** The GUI of MapGPT, was hosted within the Zeitlinie GIS, as depicted in Figure 5.3. The top app bar includes various functional buttons, such as settings and a share feature, allowing users to customize their experience and easily share map data. The central feature of the interface is the Map Display, dedicated to presenting the GIS data in a visually engaging and interactive format. At the bottom, the Bottom App Bar is strategically placed at the lower edge of the interface. It features visibility control buttons on the left and a floating action button on the right, which toggles the visibility of the MapGPT interface window. Additionally, the left edge of the map accommodates a control panel, a key, and a list of tram lines, all of which contribute to the functional richness of the interface. To ensure a clear view of the map, all panels are designed to be retractable, allowing users to hide them as needed and enjoy an unobstructed map display.

For the audio user interface, upon activation of voice recognition and the user's granting of permission for the browser to access their audio input device, an event listener is initiated to detect the wake word "Question." Subsequently, the client displays the user's spoken input in real-time within a text area. Should users observe any inaccuracies in the transcription, they are able to terminate MapGPT's listening session by stating 'Abort', which results in the clearing of any text from the text area. Upon cessation of the user's utterances, MapGPT automatically transmits the captured text to the backend, simultaneously deleting the input from the text area. Subsequently, the spoken response

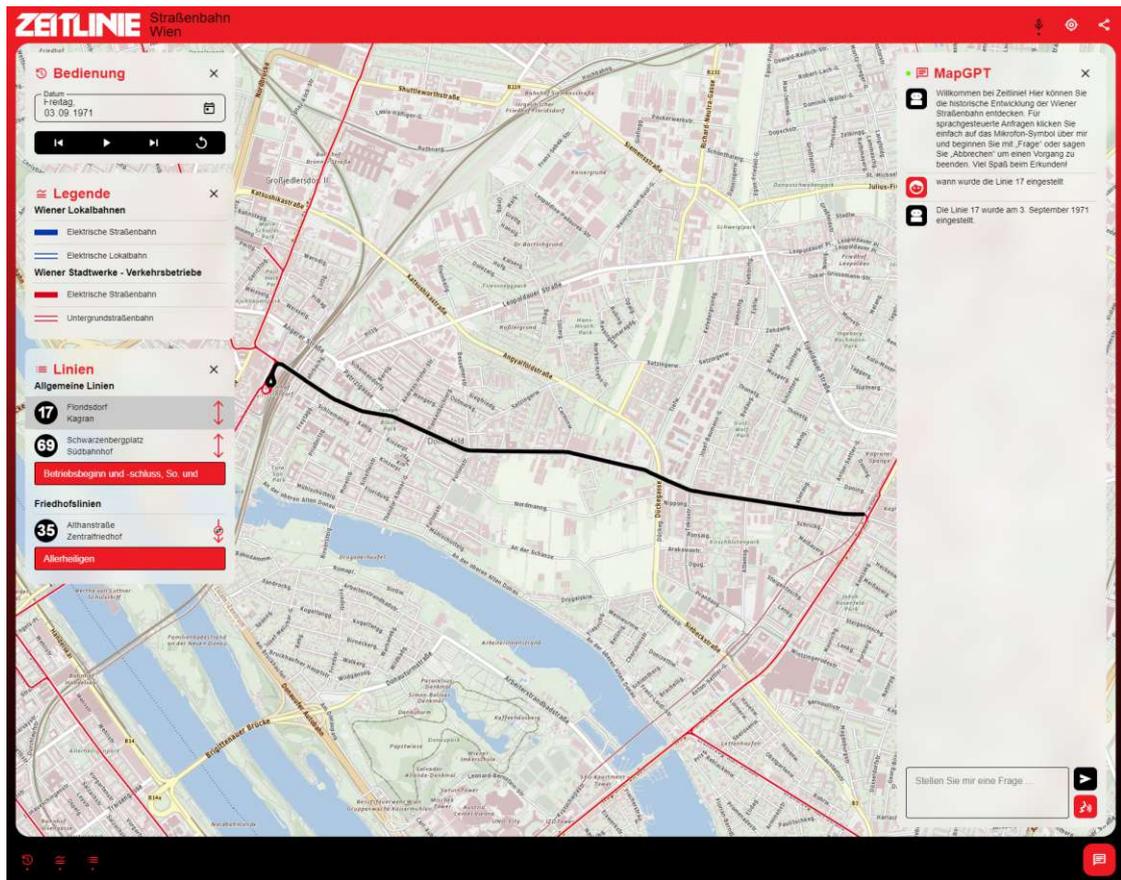


Figure 5.3: Zeitlinie GUI with MapGPT to the right. A tram line was selected, highlighted, and centered on 3 September 1971 after a MapGPT query.

is audibly delivered once the front end retrieves the corresponding response object. The process makes use of the Web Speech API for speech recognition and the Web Audio API for playback, thereby ensuring seamless integration of these technologies into the user interface.

### 5.1.3 User Study

A usability study was designed with the objective of assessing Mapgpt. The participants were assigned specific tasks to perform using the prototype, enabling us to identify the extent to which participants were able to utilize the system in order to achieve the desired outcomes. To ensure the accurate pronunciation of local street names, which may be problematic in English due to potential speech recognition issues, the study was conducted in German. The study sessions were conducted online via Zoom, with each session lasting approximately 30 minutes. While lab research provides more control, using Zoom allowed for broader participation, and reduced scheduling barriers. Also, remote usage was chosen

to better reflect the real-world contexts in which users would naturally engage with these informational companion systems. The session comprised the completion of six tasks, followed by the completion of a questionnaire and a brief discussion. The discussion aimed to gather participants' feelings about communicating voice-to-voice with the LLMs, their overall experience, and any potential improvement ideas. It was necessary for participants to utilize the Chrome browser and have a functioning computer microphone.

## Participants

The participants were primarily students enrolled at the university, secondarily, individuals with an interest in public transport in Vienna who were recruited through various channels. A total of 37 individuals participated in the user study. Of the total number of participants, 3 were female and 34 were male. The 4 male participants were recruited from outside the university, while the remaining 33 were undergraduate students in the field of informatics. The participants were between the ages of 20 and 34 years old ( $M = 23.135$ ,  $SD = 2.451$ ). Two participants' data were excluded on the basis of technical difficulties and were considered to be outliers.

## Study Procedure

The study started with a brief introduction to the system, followed by six practical tasks, and a concluding questionnaire. Participants were presented with an introductory page that not only set the context but also included a consent form. After agreeing to participate in the study, users were provided access to the test system and introduced to MapGPT with a simple test task. This task required users to locate the main building of the university. Following this, they engaged with various functions of MapGPT, beginning with an animation playback of Vienna's tram network from 1897, and then progressing to more complex queries as outlined in Table 5.1. The design included tasks to evaluate how a conversational companion could support diverse information-seeking behaviors, ranging from temporal queries to contextual historical knowledge, within a map-based interface. This broader task setting was chosen to reflect the role of the companion as more than a spatial tool, but rather as an informative partner. The system was envisioned for a museum-like setting where visitors would engage in open-ended exploration, historical inquiry, and contextual learning rather than goal-directed map use. After completing each task, participants were required to fill out the Short User Experience Questionnaire (UEQ)[LHS08, SHT17b] and paste the assistant's output for subsequent evaluation of its correctness. Of the 13 questions pertaining to the overall user experience, 10 were derived from the System Usability Scale (SUS) [Bro96]. Three custom items were included to capture aspects of the user experience specific to the design and functionality of the MapGPT prototype, in addition to the standard 10-item SUS. These questions addressed (1) the user's preference between MapGPT and traditional search interfaces, (2) the preference for speech versus text input, and (3) satisfaction with the quality of the speech recognition. These questions were translated into German, and the phrase "this system" was replaced with "MapGPT." Participants also answered a comprehensive questionnaire

covering familiarity with related technologies, personal assessment of related skills, overall user experience with MapGPT, and demographic data. Data was collected using a locally hosted installation of LimeSurvey, which was configured to avoid collecting identifying information, thereby ensuring the anonymity of participants' identities. Observations and remarks during the sessions were documented, and the threads of interaction with MapGPT were stored anonymously.

Table 5.1: Survey tasks.

Task	Short description
1	Playback the animation from 1897.
2	List all traction methods and private operators of horse-drawn trams.
3	Change date and location, list all tram lines ever running there.
4	Find out when the switch from left-hand to right-hand drive happened.
5	Find out when line 30 was opened.
6	Find out the current network length, and the length and date of the maximum extent.

### Measurement

The results of the UEQ survey were analyzed utilizing a spreadsheet-based tool<sup>2</sup> provided by the authors of the questionnaire, available for download on their website. The SUS scores were analyzed with the SUS Analysis Toolkit<sup>3</sup>. Statistical analysis was performed using JASP<sup>4</sup>.

#### 5.1.4 Results

The objective of the usability study was to assess the overall user experience, the usability of Mapgpt companion, and several key areas, including audio input/output, natural language processing, feedback mechanisms, domain knowledge integration, and context preservation using Mapgpt.

#### Overview of UEQ scores for the Tasks

A task was considered to have been successfully completed if MapGPT accurately responded to the participant's query. Cronbach's alpha coefficients, given for the pragmatic and hedonistic qualities, demonstrate the consistency of the scales, as listed below:

- **Task 1:** Completed by all 35 participants (100%), Task 1 had the third longest average duration ( $M = 172.609$ ,  $SD = 91.061$ ). The overall quality, compared to the UEQ benchmark dataset, was excellent ( $M = 2.121$ ,  $SD = 0.660$ ). The pragmatic

<sup>2</sup><https://www.ueq-online.org/> – Accessed Dec 2024

<sup>3</sup><https://sus.mixality.de/> – Accessed Dec 2024

<sup>4</sup><https://jasp-stats.org/> – Accessed Dec 2024

quality was rated as excellent, albeit with questionable scale consistency ( $M = 2.357$ ,  $SD = 0.742$ ,  $\alpha = 0.62$ ). The hedonistic quality was also rated as excellent and demonstrated acceptable scale consistency ( $M = 1.886$ ,  $SD = 0.977$ ,  $\alpha = 0.76$ ).

- **Task 2:** Achieving a completion rate of 97.1% by 34 participants, Task 2 was completed in the second longest duration ( $M = 174.434$ ,  $SD = 75.225$ ). It was rated excellent in overall quality ( $M = 2.100$ ,  $SD = 0.851$ ). Both the pragmatic ( $M = 2.582$ ,  $SD = 0.743$ ,  $\alpha = 0.80$ ) and hedonistic qualities ( $M = 1.618$ ,  $SD = 1.185$ ,  $\alpha = 0.83$ ) exhibited excellent assessments with good scale consistency.
- **Task 3:** Completed by 29 participants (82.9%) in the longest duration ( $M = 267.214$ ,  $SD = 107.547$ ), Task 3 was rated excellent in overall quality ( $M = 1.875$ ,  $SD = 0.987$ ). Both the pragmatic ( $M = 1.875$ ,  $SD = 1.230$ ,  $\alpha = 0.87$ ) and hedonistic qualities ( $M = 1.875$ ,  $SD = 1.091$ ,  $\alpha = 0.88$ ) showed excellent results with good scale consistency.
- **Task 4:** All 35 participants (100%) completed Task 4, which had the second shortest duration ( $M = 78.993$ ,  $SD = 36.408$ ). The overall quality was rated as excellent ( $M = 2.196$ ,  $SD = 0.775$ ). The pragmatic quality was excellent with acceptable consistency ( $M = 2.743$ ,  $SD = 0.521$ ,  $\alpha = 0.77$ ), and the hedonistic quality was excellent with good consistency ( $M = 1.650$ ,  $SD = 1.183$ ,  $\alpha = 0.81$ ).
- **Task 5:** Also completed by all 35 participants (100%), Task 5 had the shortest duration ( $M = 56.514$ ,  $SD = 23.986$ ) and was rated excellent in overall quality ( $M = 2.127$ ,  $SD = 0.871$ ). The pragmatic quality was excellent with acceptable consistency ( $M = 2.796$ ,  $SD = 0.484$ ,  $\alpha = 0.72$ ). The hedonistic quality was rated as good with good scale consistency ( $M = 1.457$ ,  $SD = 1.449$ ,  $\alpha = 0.89$ ).
- **Task 6:** Completed by 31 participants (88.6%) in the third shortest duration ( $M = 126.125$ ,  $SD = 47.581$ ), Task 6 showed excellent ratings in overall quality ( $M = 2.186$ ,  $SD = 0.742$ ). The pragmatic quality was excellent with excellent consistency ( $M = 2.582$ ,  $SD = 0.776$ ,  $\alpha = 0.91$ ), and the hedonistic quality was also rated as excellent with good consistency ( $M = 1.789$ ,  $SD = 1.080$ ,  $\alpha = 0.88$ ).

### System Usability

MapGPT achieved a SUS score of 84.07, with a median score of 87.5 and a standard deviation of 9.75. This places it in the 94<sup>th</sup> percentile according to the benchmark of 5000 scores compiled by Sauro and Lewis (2016), giving gives MapGPT an A [SL16]. Thus, the SUS score, placed in the upper percentile, reflects high usability (see Figure 5.4). In line with the results, many participants commented positively on the usability of the system. p21 found it *‘very easy, [and] self-explaining*, p10 had a *‘very good [user] experience’*, and p4 as well as p34 praised the *‘clear GUI’*. Despite the favorable outcomes of the query function and system usability analyses, a few participants identified potential areas for enhancement. One requirement stated by participants p15 and p35 was the

ability to cancel or mute the audio output entirely. p8 suggested a better differentiation between user and assistant messages akin to common messenger services. Lastly, having to enable voice recognition with a button that is situated outside the MapGPT section was deemed as *‘counter-intuitive’* by p5.

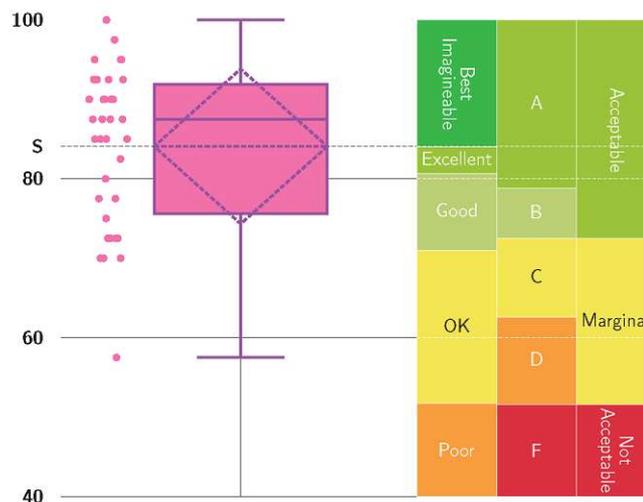


Figure 5.4: SUS analysis, Scores below 40 omitted,  $S = 84.07$  [BBP22].

### Feedback on Functionalities

**Audio Input and Output:** Voice input was broadly accepted. Despite its high usage rates—ranging from 88.6% in tasks involving contextual data changes to 97.1% in specific operations—preferences for voice-over text were less favorable. A majority of participants expressed a preference for text, with 74% disagreeing with a preference for voice. This aligns with the reported usage frequency, where 40% indicated they use voice input less than several times a year. Notable complaints concerned the need for improvement in voice recognition accuracy and speed, particularly for those with accents or dialects. For example, p33, a non-native speaker of German, wrote that *‘[it] is a bit bad for persons with poor pronunciation.’* The participants expressed appreciation for the natural language audio output, despite some criticism regarding pronunciation issues, such as incorrect number enunciation. The interactive dialogue capability of the system, which emulates interactions with well-known voice assistants, was generally well-received. However, some users found it unconventional. With p22 calling it *‘very funny’*, and p29 stating that the *‘conversation [was] relatively normal, like with Alexa or Siri’*, a majority of participants expressed satisfaction at the prospect of engaging in a genuine dialogue with Mapgpt companion.

**Natural Language Queries:** 97% of participants reported frequent use of map-based applications at least once per week, demonstrating high familiarity. 85% used AI chatbots such as ChatGPT with similar frequency. Participants showed a robust preference for

natural language over logical queries, with 63% favoring MapGPT. They reported not feeling overwhelmed by traditional search forms. As p24 reported *‘Even when questions were transcribed wrongly sometimes, it still delivered the correct answer.’* However, there were also calls for improvements in question recognition, indicating some inconsistencies. Currently, OpenAI’s assistant API restricts queries to one function at a time. This limitation was particularly evident in tasks requiring simultaneous adjustments, such as Task 3 (date and location change), leading to frustration among users, who desired multi-query functionality. Nevertheless, some participants requested that the assistant perform both actions simultaneously which resulted in either a change of date or location or a loss of connection due to a server error. Misunderstandings often result in partial task completion or system errors.

**Feedback Mechanisms:** MapGPT lacks an obvious listening indicator and acceptable disconnection handling. Whilst p13 finds MapGPT to be *‘surprisingly well realized’*, they also stated that there should be a better graphical indication when the assistant is listening. Currently, the system initially shows that it is listening by changing the placeholder text of the text field to ‘I am listening ...’, and subsequently replacing this with the live user transcript. In the event of a disconnection with the server, an indication was provided to the user by a red dot adjacent to the MapGPT section heading and the deactivation of the text field, speech, and send buttons. Upon encountering this situation, none of the participants observed the changed placeholder, which had been set to ‘I am currently not available. Maybe try to reload the page!’ p20 stated in the optional improvements text field, that *‘There was once a crash/connection failure with MapGPT. Perhaps it would have been better to draw the user’s attention to this, as I would not have realized it immediately.’* p18 said that having to reload the page to reconnect is *‘questionable’*.

The majority of participants (80%) indicated that they were familiar with the public transport system in Vienna. Furthermore, the majority of participants (40%) reported using public transport in Vienna on a daily basis, while 48% reported using it several times per week and 6% reported using it at least once per week. However, of the 35 participants, only a minority of five (14%) agreed to have in-depth domain knowledge about the tram system in Vienna. A majority of participants did not challenge the responses provided by MapGPT, either verbally or in the questionnaire. It was only during the third task, which required the participants to change the date and location and to ascertain which tram lines had ever operated at Praterstern (a well-known transportation hub in Vienna), that some of them began to examine the responses in greater detail. p16 commented negatively about the reliability of MapGPT’s responses overall, stating that *‘I have not had the opportunity to check the answers. In general, it would be important to know whether you can rely on the answers.’*

**Domain Knowledge Integration:** The integration of domain knowledge references MapGPT’s connection to its host GIS by eight predefined query functions. The efficacy of the system was evaluated in six distinct tasks. A task was considered complete when

the response provided by the assistant to the participant's query was accurate. In 94.7% of the 210 task executions, MapGPT provided the correct response.

**Context Preservation:** The participants were required to change the date to any day in 1935, the location to Praterstern, and request that the assistant provide a list of all lines that had ever run there for the third task. Two distinct methodologies were available for the retrieval of this data and the subsequent modification of the map view. The more expedient approach was to utilize the 'tram lines' filter, providing MapGPT with the location and date in a single query. Alternatively, the date and location change query functions could be employed independently of the filter function, with the previous inputs referenced. The majority of participants employed the second approach, which confirms the effective maintenance of context in these dialogues. For example, p28's approach to the task was as follows:

**Participant (P):** Show me Praterstern.

**MapGPT (M):** I fly to the location of Praterstern.

**(P):** On 1 January 1935.

**(M):** Let me show you 1 January 1935.

**(P):** Which lines have run here over the course of time?

**(M):** The lines 15, 3, C-5, CA, and CT ran at Praterstern over time.

### 5.1.5 Discussion

Overall, Mapgpt companion has very good usability. Our findings demonstrate the feasibility of voice input, as evidenced by QuickSet, MATCHKiosk, and several concepts proposed in the 2000s [CMO<sup>+</sup>99, CMC00, KKYS02, RSF<sup>+</sup>03, JB04]. Furthermore, participants were delighted about the possibility of conducting an actual voice-to-voice dialogue. One of them even went as far as to say that the *'natural voice is better than Google Translate'*. This corroborates the hypothesis put forth by Kim et al. (2018) and colleagues in their paper on voice input and chatbots, namely that two-way audio would engender a sense of authenticity in participants, akin to that of a genuine conversation [KGJ18]. Many participants expressed a preference against text-to-speech input in the post-test questionnaire, a result that was unexpected. This disfavor may be attributed to the infrequent use of voice input, with the majority of participants reporting usage less than several times per year. It is possible that participants perceived the question as pertaining to general usage rather than specifically to GIS search tools. 63% of participants preferred MapGPT over traditional search tools. It is probable that this is the result of the effortless formulation of normal sentences as query input on the fly, as shown by the bad results of novice users who rarely utilized logical queries by Audet and Abegg [AA96].

Participants also pointed out the easy, self-explaining usability and tidy appearance of MapGPT in several comments. These positive results showed that the adherence to

common design guidelines (Google’s Material Design 3) accomplishes easy and intuitive GIS applications [LDV11]. Participant’s comment about the reliability of responses needs further consideration: *‘I have not had the opportunity to check the answers. In general, it would be important to know whether you can rely on the answers.’* A broader question would be why the assistant has selected a specific query function to be carried out by the server, as this can be erroneous sometimes. There is an existing proposal by Wachter et al. (2017) for counterfactual explanations, which are feasible without the necessity of directly accessing or modifying the underlying mechanisms of the AI system in question [WMR17]. These would clarify the rationale behind the assistant selecting a particular function based on the recognized parameters, which should be relatively straightforward for current LLMs to accomplish. As users should feel confident and reassured in their actions and progress [Bro09, LDV11], this is a very important improvement to be included in future iterations and map-based AI assistants. MapGPT proved that the domain knowledge integration performs to a satisfactory degree, based on the overall correct responses in 94.7% of all task executions. This also demonstrates that the alignment of professional and universal knowledge, as proposed by the creators of GeoGPT, is feasible and yields satisfactory outcomes [ZWW<sup>+</sup>23]. The following summary of the key points of the usability study provides an overview of the key findings:

- Voice input is accepted, even when participants did not regularly use this mode before.
- Natural language voice output is greatly appreciated.
- MapGPT is preferred to traditional search tools.
- Participants require the possibility to ask multiple questions or execute multiple commands per query.
- MapGPT, as a map-based AI assistant, has very good usability.
- Participants require the addition of a mute button for the voice output, and the grouping of all graphical interface elements of MapGPT in the same area.
- Participants require an adequate listening indicator, disconnection handling, and the possibility to check the reliability of responses.
- MapGPT’s integration with the domain knowledge of the host GIS worked in a majority of tasks performed.
- MapGPT successfully preserved context during its conversations with participants and also accessed past queries for input parameters.

The overarching objective of this research was to provide recommendations for future map-based AI assistants by identifying user preferences. Map and GUI usability go hand

in hand, one should not take precedence over the other as both collectively affect the system's user experience [MMKM17]. The GUI should be designed in a way that allows users to maximize the map area, as this was shown to be a natural behavior by both novice and expert users as shown by [HZ08]. Future applications should provide users with easy-to-learn query or search tools to encourage novice users [LDV11]. Integrating LLMs into the system allows natural language queries by novice and expert users alike. In addition, LLM assistants enhance the quality of responses to user queries by providing answers in natural language. The AI based assistant should tap into the domain knowledge stored in the GIS database and provide meaningful feedback and responses for the users, replacing traditional search tools. Context preservation allows users to formulate follow-up questions easily. Users should be able to trust the responses when interacting with the AI assistant. This can be implemented by providing counterfactual explanations in the form of highlighted parameters that the assistant recognized in the user input or by storing citations for domain knowledge in the database and returning them accordingly. It is recommended that voice input and output be implemented as core components of the system interface. Combining LLMs with a system's domain knowledge and voice-to-voice communication greatly benefits the usability of the GIS application.

### Limitations

The majority of participants were enrolled in undergraduate computer science studies, which may result in an overestimation of MapGPT's usability for a general population. Given that the participant age group was between 20 and 30 years old, it is unclear whether the results are applicable to the older population as well. The exclusive usage of the Chrome browser is a technical limitation due to its support for client-side functions such as voice transcription and audio output. Consequently, future versions of MapGPT should provide support for further common browsers across operating systems. Future studies may also employ qualitative assessment methodologies to gather more in-depth insights. The total cost of the three-month development and subsequent study was \$68.57, with \$1.15 allocated to the text-to-speech model and the remainder to the assistants interface. While the development phase was relatively inexpensive, at a total cost of \$11.12, the study with 37 participants incurred a cost of \$57.64. If MapGPT were to be released to the general public at the current pricing levels, it would not be financially viable for a private individual or small enterprise to operate, assuming regular usage of more than a few requests per week. Two avenues for further research emerge from this context: firstly, at what level of system complexity is a map-based AI assistant capable of operation, and secondly, what are the potential avenues for improving the affordability, performance, and resource efficiency of LLMs and text-to-speech models for local operation on a server?

#### 5.1.6 Conclusion

Our work demonstrates the effectiveness of Mapgpt companion, an AI-driven map assistant, in enhancing the user experience for GIS applications through intelligent,

voice-activated interfaces. The results of our user study, which involved 35 participants, demonstrated the utility of integrating LLMs to simplify complex GIS interactions into conversational engagements that users found intuitive and engaging. The results demonstrated the user-friendliness of MapGPT, as evidenced by the favorable SUS and UEQ-S scores. MapGPT represents a significant step forward in the design of interactive, user-friendly GIS applications, integrating AI's robust analytical capabilities with user-centered design principles. Nevertheless, our investigation also highlights the necessity for continuous enhancement, particularly in the domains of error management, multi-modal feedback, and the augmentation of natural language processing capabilities to accommodate diverse user accents and linguistic nuances. Despite the system's strengths, it is important to acknowledge certain limitations. One such limitation is the sample size and composition, which consisted mainly of younger, technologically adept users. Future research could be expanded to include a more diverse demographic in order to gain a more comprehensive understanding of the usability of the system. By transcending the limitations of conventional GIS applications, MapGPT not only enhances accessibility but also expands the scope of interaction with AI, thereby establishing a new benchmark for future advancements in this field.

## 5.2 Carbon Rebellion Companion

This chapter is based on our following publication:

### Publication

Shahu, A., Wölfer, M., & Michahelles, F. (2024). Carbon Rebellion: Empowerment using Data-Driven Narratives. *ACM Journal on Computing and Sustainable Societies*.

The issue of climate change is increasingly being characterized as a "wicked problem" [Inc16, LCBA12]. Wicked problems are those related to social-ecological systems that are complex and poorly defined, often involving conflicting information and disagreements among stakeholder groups regarding norms, values, and goals [Xia13, ABLPS14]. They share several common traits, including a) the values held by stakeholders in conflict evolve over time and among different groups b) both the problem itself and its potential solutions are not straightforward or determinate. As a result, climate change emerges as an urgent and formidable challenge humanity is facing today, primarily driven by human activities such as fossil fuel consumption and deforestation [CSB<sup>+</sup>14]. These actions have far-reaching consequences, posing threats to both natural ecosystems and human societies. These threats manifest in the form of more frequent extreme weather events, rising sea levels, and increased food insecurity [BVA<sup>+</sup>]. Achieving the ambitious goal of limiting global warming to 1.5°C above pre-industrial levels requires profound and rapid transformations in the way societies operate. However, assigning accountability to address this global issue frequently encounters political resistance, becoming a contentious issue among stakeholders including consumers, industries, governments, and corporations [Dou10]. Organizations and societies frequently engage in unpredictable and inconsistent

environmental actions due to their struggle to comprehend the intricate challenges they confront.

Effectively engaging with climate-related issues hinges on acquiring a comprehensive understanding of the subject [HvdLC12]. Awareness can play a vital role in addressing these issues, presenting various forms of learning that can dismantle unsustainable practices and foster more sustainable ones. The Intergovernmental Panel on Climate Change (IPCC) serves as a prominent source of climate change information, which then circulates in policy, the media, and the public [PNV<sup>+</sup>20]. The IPCC produces Assessment Reports (ARs) that consolidate climate change research, presenting information in a descriptive and explanatory manner. Additionally, these reports feature "Summaries for Policymakers" (SPMs), which translate the detailed scientific content into more accessible language for non-expert audiences [BDMS<sup>+</sup>16]. However, the reports can be too complex for non-experts and younger audiences, making them skeptical and apathetic [HLSC20]. This highlights the ongoing need to find better ways to communicate science to the public [FH19, LMR<sup>+</sup>20].

Education plays a pivotal role in addressing this challenge, and experts argue that the field must undergo revision and restructuring to provide conditions for transformative learning and meaningful climate action [MPO<sup>+</sup>19, ORC<sup>+</sup>13, SO01]. Typically, climate change education is confined to the natural sciences, often focusing solely on explaining the greenhouse effect and discussing the potential consequences like rising temperatures, altered precipitation patterns, and sea-level rise [MPO<sup>+</sup>19, SNW17]. This conventional approach primarily conveys messages of fear rather than providing real-life examples for active engagement. Additionally, this approach fails to empower individuals as stakeholders, lacks the capacity to inspire action, and misses an opportunity for deeper community engagement and discussion. Consequently, it has faced criticism for potentially contributing to feelings of denial, desensitization, and apathy [Nor11, Sto15]. Research indicates a growing sense of pessimism and hopelessness regarding climate change and the future among young people [Oja12]. Mainstream media frequently feature stories regarding climate anxiety, eco-anxiety, and climate grief, to the point where *Grist* magazine dubbed climate anxiety the "biggest pop-culture trend" of 2019 [McG19]. It's evident that there is a necessity to change how we discuss and educate about climate change. Also, the role of individual actions in addressing climate change is a topic of ongoing debate, with discussions occurring not only within the scientific community but also within the daily lives of people [WZD20, WN17, BVA<sup>+</sup>20].

Wynes and Nicholas propose that while individual actions may appear inconsequential, even minor changes made by individuals can collectively contribute to a substantial reduction in greenhouse gas emissions [WN17]. Furthermore, in his article titled "Multiplication Saves the Day" <sup>5</sup> McKibben argues that striving for maximum sustainability as an individual may be difficult to measure. However, if that same individual persuades their friends and family to engage in a single climate-friendly action, the impact becomes quantifiable through the power of multiplication.

<sup>5</sup><https://orionmagazine.org/article/multiplication-saves-the-day/> – Accessed Dec 2024

Scholars have extensively explored storytelling as an effective method of scientific communication. Stories not only align with the innate way people process information [BBP20, Fis84] but also enhance information comprehension and retention while fostering changes in beliefs, attitudes, and behaviors [Dah14, MCM17, MS99, MCC<sup>+</sup>19, BBP20]. However, despite these findings, some researchers advise caution when employing storytelling in science, often citing the imperative of maintaining impartiality and objectivity [BFvdL<sup>+</sup>20]. This requirement aligns with the IPCC's articulated objectives of delivering "clear and balanced information" that is "pertinent to policy without advocating for specific policies" [SQP<sup>+</sup>14]. When utilizing conventional storytelling structures, it's crucial for these narratives to present accurate and fact-based arguments. As Boyd et al. (2020) argued, even within the realm of science, "factual accounts are likely less story-like but are still narratives nonetheless [BBP20]." Meaningful climate action necessitates evoking an emotional response, which we argue can be achieved through fact-based narratives. We investigated the following:

- **RQ1:** How can we create an engaging climate change narrative that shows the seriousness of the issue, and suggests ways for individuals to get involved?
- **RQ2:** To what extent do personal anecdotes combined with data-driven narratives impact the user engagement level?
- **RQ3:** How does interaction with a data-driven narrative influence an individual's attitude and behavior towards climate action?

Our research aims to educate individuals on the critical issue of climate change by sharing narratives that offer a variety of viewpoints from different stakeholders, utilizing the "Carbon Rebellion companion" as illustrated in Figure 5.5. The objectives of this work are to inspire and empower participants, foster a sense of agency in climate action, and highlight the effectiveness of community-based efforts. The game-based narrative companion, Carbon Rebellion, features diverse challenges related to daily life choices in food, transportation, and waste management. It highlights the importance of personal choices while also stressing the necessity of acknowledging their limitations when taken in isolation.

Wynes et al. (2020) suggest a clear connection between hope and pro-environmental actions, emphasizing the critical role of maintaining agency and optimism in tackling climate change [WZD20]. Similarly, Ogunbode et al. (2022) propose that media exposure, along with the resultant feelings of anxiety and concern, may motivate individuals to engage in climate action [ODH<sup>+</sup>22]. The COM-B model of behavior, which identifies capability, opportunity, and motivation as essential for any behavior to occur, complements our understanding of climate action motivations [WM20]. West and Michie suggest that behavior is part of a dynamic system with both positive and negative feedback loops, where these factors interact over time [WM20]. Specifically, motivation—is central to the model, explaining how reflective thought processes and emotional and habitual processes converge

to influence behavior. Through this comprehensive approach, integrating emotional and reflective processes, we can foster climate-positive behaviors. While motivations can vary widely among individuals, our literature review suggests that effectively educating people about the reality and severity of climate change, coupled with presenting viable solutions rather than focusing solely on negative outcomes, may be most effective in motivating individuals to participate in climate actions.

Achieving a sustainable future requires that personal choices be integrated with broader societal transformations and supportive policies. By fostering a community that embraces small actions, such as reducing meat consumption or using public transportation, we can collectively make an impact. Therefore, the integration of an Interactive Digital Narrative within this context aims to provide a realistic depiction of climate change challenges while also enhancing individual engagement through compelling storytelling and interactive gameplay. Our research highlights the significance of presenting an honest portrayal of the severity of climate change alongside actionable strategies to promote individual involvement. We were interested in figuring out if using game elements and storytelling can make people more interested and motivated to take real action. As the game engages with emotions and subversion, we are particularly interested in understanding how the game impacts its players, not just educationally but also emotionally, with the potential to shift perspectives. Findings from our study indicated that Carbon Rebellion companion (1) fostered critical thinking, (2) evoked emotional responses, (3) promoted a drive for climate action, (4) provided insights into primary climate change contributors, and (5) encouraged individuals to support community climate initiatives. It's important to note that our game-based narrative approach is not a comprehensive solution, but rather an effort to raise awareness and stimulate meaningful discussions.

### 5.2.1 Background

Addressing climate change requires effective communication and education to catalyze behavior and lifestyle adjustments. Environmental communication aims to share information and behaviors that are good for the environment, while pro-climate communication focuses on convincing people to take actions that reduce greenhouse gas emissions[HMCA23]. Despite abundant information, many climate communication strategies have faltered due to their unidirectional message delivery, lack of context, and predominantly negative tone [AS12, Coo11, MD11, Sch12]. Blevis explored significant questions related to the importance of design in sustainability, extended the concept of sustainability beyond environmental concerns to include human factors and international relations, emphasized the utility of photographic methods in design understanding, reconsidered design principles with an emphasis on durability and thoughtfulness, and proposed hypotheses about the impact of design details on global attitudes and policies, all united by their ambitious nature [Ble18].



Figure 5.5: On the left, the landing page of the narrative; on the right, the community impact background, with a highlighted user quote: *"If everyone works together, something can actually happen."*

### Narratives and Storytelling

The use of storytelling and narrative is effective in communicating complex scientific information to non-experts, especially in the context of controversial topics like climate change, and it aligns with the communication preferences of the digital-native generation. This approach makes scientific subjects less abstract and more relatable, bridging the gap between large-scale phenomena and human-scale experiences. As indicated by Dahlstrom [Dah14] and further supported by the National Academy of Sciences [NAoSM<sup>+</sup>17], previous work highlights the effectiveness of employing storytelling and narrative in conveying scientific information to non-experts. This approach is situated within the broader framework of "framing," which is an important feature of public outreach. The complexities involved extend beyond the challenges associated with the scientific subject matter alone. They encompass varying audience requirements and viewpoints, as well as the belief systems or "mental models" individuals rely on to make sense of the world. This becomes particularly significant when presenting data related to controversial subjects like climate change, energy, or food safety [NAoSM<sup>+</sup>17]. In light of these challenges, high schools are actively seeking ways to modernize their knowledge transfer methods, recognizing the need to align with the communication preferences of the "interactive generations" [AG11] or "digital natives" [Pre01], who have grown up immersed in a digital world characterized by computers, the Internet, and video games, and have a natural affinity for concepts such as interaction, participation, and collaboration.

According to the rhetorician Fisher (1984) [Fis84], stories are critically adopted by audiences who perceive some stories to be more reasonable than others. Narratives characterized by high rationality exhibit both internal coherence or probability (where story elements cohesively connect) and external fidelity (where the story resonates with people's real-life experiences). This fidelity serves to render subjects like climate change less "abstract and intangible," as it bridges them with the lived experiences of audiences [Fis84]. By telling concise, cogent, and pertinent stories, narrative likelihood and fidelity can be improved [BM21a]. The "narrative policy framework" is used by researchers to identify the four structural components that all stories share: characters, setting, plot, and

the moral of the story [JP17]. Narratives are frequently compared to other communication genres, such as expository or argumentative communication, or with different explanations, such as statistical, logical, or descriptive [AO09, NGS<sup>+</sup>05]. Narrative communication is context-dependent due to the continual cause-and-effect structure of the temporal events it is composed of [TS85, Dah10, Dah12]. These characteristics are identified in other studies as common elements of stories that influence audience engagement [BBP20]. Glaser et al. (2009) describes four aspects that narratives provide that may boost knowledge acquisition about science when compared to a typical expository curriculum: dramatization, emotionalization, personalization, and fictionalization [GGS09]. Some studies have experimented with narrative elements to see how changing isolated aspects of stories affects narrative engagement. For example, research has revealed that changing the temporal state of stories (i.e., past, present, or future) and their realism (i.e., realistic or fantastical) changes how individuals engage with stories [KN19, SB18]. Furthermore, it was discovered that narrating in the first-person, third-person, or bystander viewpoint affects persuasive consequences [QJSP21].

In our research, we utilized the strengths of narrative coherence and resonance to effectively convey the complex issue of climate change. Additionally, we employed narratives to explain phenomena that couldn't be directly experienced due to the scales involved, such as climate change, parts per billion, or events thousands of years in the future. When trying to grasp these concepts, audiences had to relate them to aspects of their everyday experiences and extrapolate beyond those familiar boundaries to form a general understanding on which they could base their decisions. Construal theory [MS11a, TLW07], elucidates how changes in perception can be influenced by the scale of an event. It suggests that events perceived as more psychologically distant and thus removed from the immediate human scale tend to elicit more abstract and emotional responses compared to those with less psychological distance. Therefore, in the context of our research, narratives emerge as a promising yet relatively understudied communication tool for bridging the gap beyond the human scale. It offers a means of packaging complex phenomena into a format that aligns with human-scale experiences, potentially addressing the challenges of effectively conveying the community impact of climate action.

### **Personal Accountability and Consciousness**

Fostering environmental consciousness holds critical importance in light of the growing global environmental challenges. Mere awareness of environmental problems often falls short of inspiring eco-friendly actions. It's important not only to be aware of environmental issues but also to actively engage in environmentally friendly behaviors and practices. Comprehensive environmental awareness by itself may not necessarily lead to environmentally friendly behaviors [HHT87, KA02, FKW04, ASVR07]. On the other hand, recognizing the role of personal actions in contributing to environmental degradation can serve as a catalyst for individuals to adopt more sustainable behaviors [HHT87]. Factors such as behavioral intent can exert a significant influence on steering individuals towards the adoption of eco-friendly behaviors, as evidenced by prior research [SB64,

Sto17]. Previous work has highlighted the effectiveness of well-integrated environmental consciousness components. For instance, one study demonstrated that a combination of factors, including personal responsibility, environmental awareness, and values, could explain a substantial portion (76-94%) of ecological behaviors [KRHB99]. The stage model of self-regulated behavioral change suggests that recognizing personal accountability for the environment and comprehending one's adverse impact on it serves as a pivotal initial step in engaging in pro-environmental actions [Bam13]. These individual environmentally conscious norms have been associated with behaviors such as selecting sustainable transportation alternatives [HBMH01] and actively participating in the preservation of marine ecosystems [CM03b]. Despite the existence of numerous behavioral models designed to explain and predict both mitigation and adaptation behaviors, there has been minimal adoption of more integrative and interdisciplinary frameworks like the attitude-behavior-context (ABC; [Ste00]) or the capability, opportunity, motivation-behavior (COM-B; [MVSW11]) models by psychologists focusing on climate action. Whitmarsh et al. (2021) contend that the effectiveness of these models in driving meaningful change is constrained because they tend to be overly simplistic, individualistic, linear, and deliberative, and they often overlook the environmental impacts [WPC21]. However, Environmental Sustainability Education (ESE) goes beyond simply raising awareness of environmental issues [Jan20]. It aims to shape attitudes and promote lifelong pro-environmental behaviors, which are particularly challenging to foster. To address this, Digital Game-Based Learning (DGBL) is employed as a potent pedagogical tool within ESE. DGBL not only imparts cognitive knowledge but also emotionally engages learners by allowing them to experiment with new behaviors and witness immediate consequences [Jan20].

Howarth examined the utilization of narratives to actively involve the public in co-creating more sustainable, low-carbon futures, with a specific focus on the positive aspects, emphasizing the departure from linear information transmission in favor of emphasizing overlaps in perceptions, values, and motivations to facilitate constructive dialogues and opportunities for social transformation [How17]. Mohanty found that providing information about CO<sub>2</sub> emissions, particularly in terms of CO<sub>2</sub> by weight, and using various framing contexts can significantly influence people to make eco-friendly choices in transportation, emphasizing the importance of improving carbon literacy and designing effective interventions to address the challenge of climate change [MFB<sup>+</sup>23]. Similarly, Alkon and Traugot examination of "place meta-narratives" within rural environmental decision-making demonstrated that establishing one's identity within a specific geographic context fostered a heightened sense of ownership and agency, ultimately leading to grassroots-driven behavioral changes, rather than relying solely on top-down policy prescriptions [AT08]. These place-based narratives were observed to exert concrete influences on individual behaviors, particularly when utilized to convey political options. Furthermore, the construction of social identities rooted in specific geographic regions significantly influenced the motivation for adaptive actions, as supported by the research of Frank and Henwood [AT08, FELC11, HPPS11]. Hence, to ensure the effectiveness of education, it should immerse individuals, evoke a sense of personal

responsibility, and empower communal initiatives, thereby fostering a deep sense of engagement [SW05, HK17, Mir91].

### Serious Game

The term "serious game" suggests a blend of entertainment with meaningful content. As defined by Mitgutsch and Alvarado, serious games provide "playful environments driven by a purpose, designed to impact players beyond the game's immediate goals [MA]." Although their concept dates back to the 1970s [Abt70], they had recently gained prominence as tools for climate education [RE]. At their core, these games maintained essential features, including engaging narratives and interactive mechanics. However, they were elevated by an added goal: to inform and convey profound messages [MA, LAD<sup>+</sup>]. Most of these games leaned heavily on simulation mechanics, presenting long-term scenarios and sometimes relying on complex mathematical models. Digital games provided unique avenues for engaging with scientific subjects, including climate communication [WS16]. They often transcended their primary entertainment purpose, acting as tools for both communication and persuasion. As suggested by Bogost [Bog10], video games embodied "procedural rhetoric," shaping players' perspectives and behaviors. Engaging with games offered rich, reflective learning experiences [Gee03]. Effective game design could lead to impactful learning outcomes [Gee08], making climate change-themed games valuable tools in science education. While games had shown potential in various settings – from enhancing climate literacy [HSMLC20, NOS<sup>+</sup>15] to promoting energy conservation [JBVB17, MPC<sup>+</sup>17], their impact wasn't consistently positive. Some faced criticism for poor graphics or limited interaction [OGPOL18], and others, like "Fate of the World" [Red11], evoked feelings of despair, counteracting their educational intent. Games such as the BBC's "Climate Challenge" [BBC06] allowed players to enact environmental reforms. Makosa et al. (2023) introduced the "Build a Smart Sustainable Windhoek" game, an interactive hybrid game that educates and raises awareness, gathers citizen input, and is highly informative in creating awareness on Smart City topics [MNU23]. Mochizuki introduced a new game design framework named CompleCSus (Complexity-Collaboration-Sustainability), based on social learning and procedural rhetoric, applied in the Water–Food–Energy Nexus Game (Nexus Game) [MMP<sup>+</sup>21]. This game explores the complexity and unpredictability of socio-ecological systems and how framing issues alongside differing values and worldviews influence decision-making, guiding the design and facilitation process to enhance collective reflection. Existing reviews of climate-centric games had limitations. While some reviews highlighted progressive game elements [OOLGP17], others cast a broader net over sustainability, diluting their relevance to climate-focused engagement [KM15, LSGT12, SKV19]. Additionally, many reviewed games seemed to have disappeared from the internet [KDV11, LSGT12, RE13]. Nonetheless, a noticeable research gap exists in understanding the potential of games to impart personal responsibility and facilitate systemic interventions related to climate change education. Consequently, "Carbon Rebellion Companion" seeks to address this gap by highlighting systemic approaches to address climate change. We incorporated a few key elements of serious games, like gamification, decision-making, and simulation, into

our narrative, rendering it interactive and captivating. Through interactive narratives like "Carbon Rebellion companion," individuals immerse themselves in environmental scenarios, actively making decisions that impact a 'CO<sub>2</sub>-Meter,' as shown in Figure 5.6a, all while maintaining a steadfast focus on the impact of collective actions without eliciting sentiments of hopelessness.

### 5.2.2 Carbon Rebellion Companion - Interactive Digital Narrative

In alignment with our objectives, we created an interactive narrative companion called '*Carbon Rebellion*'. Its companion-like qualities emerge from its ability to adapt to user choices and its role in providing contextual feedback. The system supports autonomy by offering players meaningful choices that shape their narrative path and agency in simulated environmental decisions. It promotes competence by translating abstract climate data into understandable consequences through visual feedback (e.g., the CO<sub>2</sub> meter), and relatedness by framing the user's experience within broader societal efforts and community outcomes. While it may not resemble a companion in the form of a chatbot or assistant, it reflects a broader conceptualization of companionship as guidance, presence, and shared meaning-making.

Three researchers were engaged in conceptualizing the interactive narrative, employing an iterative development process that began with rough sketching and emphasized rapid prototyping. Regular meetings were held at least bi-weekly to evaluate progress and make critical decisions. Before advancing to full development, rudimentary pen and paper prototypes were created and loaded into *Figma*<sup>6</sup> to form a semi-interactive prototype. These prototypes facilitated discussions, helped visualize ideas, and suggested potential improvements, providing a basic sense of the game flow. Realizing the need for a robust foundation in our narrative, we sought guidance from concepts in game design. We benchmarked the narrative's conceptual framework using design principles presented by Vervoort [VMvB<sup>+</sup>], which target political serious games with a focus on climate change. Furthermore, guidance was sought from a series of articles by Gamescrye<sup>7</sup>. A pivotal directive from Gamescrye's game design blog was the initiation of the developmental process with a *Vision Statement*<sup>8</sup>, facilitating a sharpened focus on the envisioned interactive narrative. Our vision statement was as follows:

*"Carbon Rebellion" elucidates the complex interplay among climate change stakeholders, pivoting attention from individual consumers to predominant polluters, and giving a holistic picture. It adeptly merges a playful approach with an empirical basis and instead portrays the repercussions of player decisions. The narrative's primary virtue resides in its capacity to mobilize players toward community actions and comprehensive climate change strategies.*

<sup>6</sup><https://www.figma.com/design/> – Accessed Dec 2024

<sup>7</sup><https://gamescrye.com/blog/> – Accessed Dec 2024

<sup>8</sup><https://tinyurl.com/VisionState> – Accessed Dec 2024

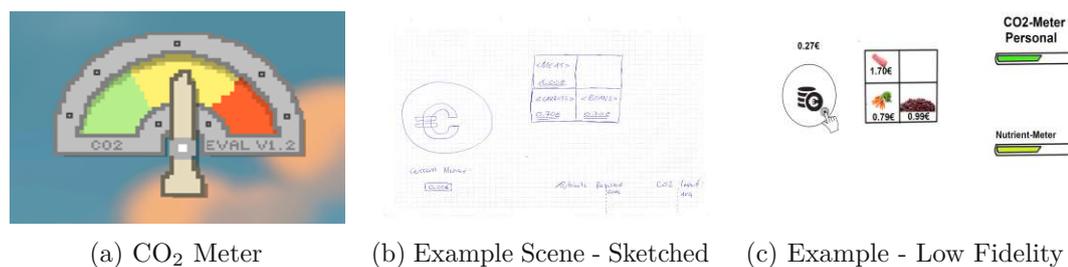


Figure 5.6: Interactive Elements and Controls in the narrative.

We made our narrative interactive by incorporating distinct mechanics into each eco-challenge quest. These quests focus on "Food," "Transportation," and "Waste Management," making environmental issues tangible by allowing players to make choices and observe their impact on a "CO<sub>2</sub>-Meter", as shown in Figure 5.6a. The interactive narrative's flow is shown in Figure 5.7. Individuals entered the narrative framework of "Carbon Rebellion," becoming immersed in the virtual world known as "Carbonia." Carbonia consisted of three distinct hubs, and participants were instructed to explore each of these hubs, as depicted in Figure 5.8a. Within these hubs, individuals engaged in three distinct eco-challenge quests centered around Food, Transportation, and Waste Management, as illustrated in Figure 5.9. These quests required personal decision-making and provided immediate feedback through the CO<sub>2</sub>-Meter. Moreover, they incentivized players to adopt more environmentally friendly practices by offering immediate feedback on their actions. Upon completion of all eco-challenge quests, the narrative transitioned to a broader perspective, offering a comprehensive overview that included various stakeholders and highlighted the impact of major players. At that pivotal moment, which we referred to as "The Twist," dramatic music was added to emphasize the delicate balance between individual actions and the broader challenges we were facing. This balance was illustrated by examining factors such as the use of private jets, the construction of new highways, and the reliance on coal plants, all of which had a significant impact on the CO<sub>2</sub>-Meter, as indicated by Figure 5.10. The narrative framework leveraged storytelling and fictional elements to enhance individuals' comprehension and emotional connection with the complex issues surrounding climate change. The narrative culminated in a climactic moment that highlighted the importance of *Community Importance* and imparted to players a *Personal Anecdote*, represented in Figures 5.8b and 5.8c. Promoting individual behaviors while conscientiously considering the influence of larger entities poses a multifaceted challenge. Our proposition of a unified community appears to offer a potential solution for achieving a sense of agency. Our narrative aimed to conclude with an optimistic denouement, avoiding a disheartening outcome. When experienced collectively as a community, this narrative highlighted the agency individuals possessed in influencing the CO<sub>2</sub>-Meter, emphasizing that individual actions, perspectives, and impacts held significance. Additionally, it emphasized how, as a unified community, individuals could exert substantial influence and contribute to systemic change.

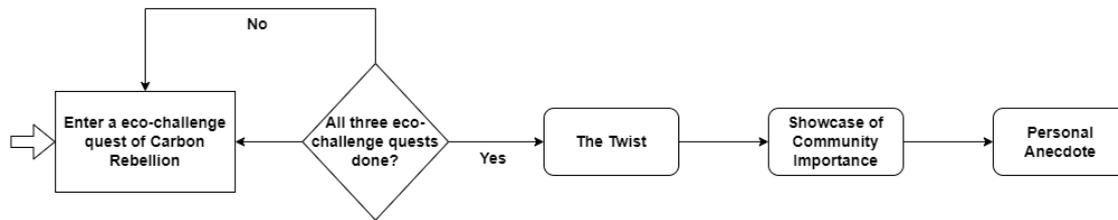


Figure 5.7: Diagram illustrating the narrative within Carbon Rebellion.

### Narrative's Mechanics

To diversify our narrative's interaction, we ingrained each eco-challenge quest with distinct mechanics, steering clear from rudimentary decision-making models like *Moral Machine* [ADK<sup>+</sup>18]. Game mechanics often take the form of *verbs* to describe the player's possible actions within the rules and constraints of the game universe [Gra14]. Each eco-challenge quest features a respective mechanic associated with its theme. Despite their different themes, they still share a common concept: present players with a scenario and have them decide on the course of action. The decision to focus on 'Food, Transportation, and Waste Management' was driven by their real-world impact, undeniable personal relevance, and tangible consequences. These three domains play a significant role in contributing to greenhouse gas emissions and climate change, as highlighted in reports by the IPCC [LCD<sup>+</sup>24]. They are not abstract concepts but integral parts of daily life. Individuals make choices every day related to what they eat, how they get around, and how they manage waste, and these choices have direct, real-world consequences for the environment. By immersing players in scenarios related to food, transportation, and waste management, we aim to bridge the gap between abstract environmental issues and personal responsibility, fostering a deeper understanding of the tangible effects of their decisions.

**Food:** Operational verbs delineating the food eco-challenge quest encompass: *Purchasing*, *Clicking*, *Weighing*. Lindrup aimed to enhance collective understanding of the climate impact of food consumption through data physicalization, resulting in the creation of Carbon Scales [LMBH23]. The study's findings emphasized the effectiveness of interactive data physicalizations in improving carbon literacy and highlighted the significance of prioritizing interaction-centered, resource-efficient design in the sustainability context. Building upon the insights gained from this study, the food eco-challenge quest's premise revolves around individuals navigating purchasing decisions within a simulated supermarket environment, taking into consideration greenhouse gas emission -estimates (GHGe) juxtaposed with the calorie density of food products. The in-game currency is accrued by interacting with an intermittently illuminating coin, comparable with mechanics in *Cookie Clicker* [Thi13]. Selections leaning towards plant-based options such as rice or vegetables induce positive feedback on the *CO<sub>2</sub>-Meter* while opting for animal-based products results in contrasting feedback.

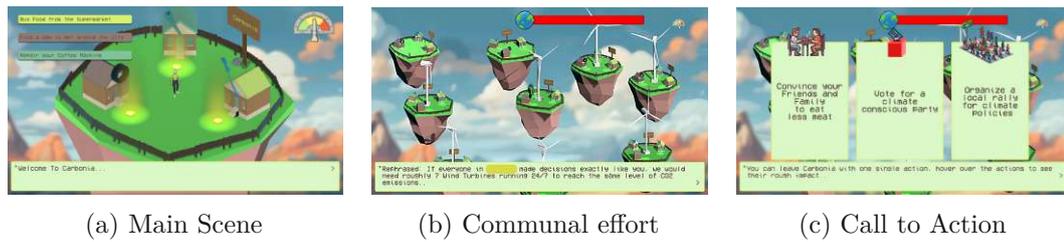


Figure 5.8: Key moments from narrative's main scene to community effort and call to action.

**Transportation:** Operational verbs for the transportation eco-challenge quest comprise: *Driving, Controlling, Experimenting*. The transportation module accentuates the juxtaposition between individual vehicular transportation and public transit. Individuals possess the flexibility to transition between these modalities and discern their respective implications. Topographic complexities vary based on the selected modality, with private cars showcasing superior speed yet buses excelling in transport efficiency. The *CO<sub>2</sub>-Meter* dynamically adjusts to reflect these choices, with the design inspired by basic obstacle navigation games.

**Waste management:** The waste management eco-challenge quest is defined by the verbs: *Solving, Clicking, Choosing*. Within the waste management segment, individuals are confronted with a malfunctioning coffee machine. The dichotomous options presented are: addressing the malfunction through puzzle-solving or opting for a replacement. The *CO<sub>2</sub>-Meter* subsequently mirrors the individual's choice, whether they be engaging in the waste management process or defaulting to the procurement of a new machine.

To further advance the development of our narrative, we utilized the circle of methodology from *The Art of Serious Game Design conceptual framework* [PCM23], which includes four primary dimensions: *Storytelling, Learning, Gameplay, and User Experience*. This model consists of three concentric circles within each dimension for an in-depth game analysis. The approach involves answering specific questions (e.g., *How will the story end?*) and positioning the response within the appropriate segment on the circle of methodology. Implementing this technique surfaced new questions and refined Carbon Rebellion companion. Two researchers underwent iterative cycles using this model, initially sketching scenes and later developing the narrative, as illustrated in Figures 5.6b and 5.6c. One of Carbon Rebellion's guiding principles was to make the narrative's outcomes largely independent of the player's skill level. Our goal was to encourage critical thinking and stimulate discussions among a wider audience, including those less experienced with gaming.

## Prototyping

Our objective was to facilitate individuals in attaining an enhanced sense of personal agency within the framework of a plausible narrative. For the narrative to achieve its intended purpose, it must articulate the urgency and gravity of the situation, yet concurrently retain a constructive undertone that highlights feasible solutions. While the narrative's themes are fictionalized, they are anchored in real-world data for authenticity. Values in the game are presented as deviations from Austria's average, emphasizing relative rather than absolute impact. Please note that all calculations in this dissertation were performed using the German numbering conventions, and we utilized data specific to Austria, sourced from databases that employ the German numbering conventions. The primary difference between German and English numbering conventions is that German uses a comma as a decimal separator and a period for thousands, whereas English uses a period as a decimal separator and a comma for thousands.

**Food/ Supermarket:** For the food eco-challenge quest, we utilized pertinent data to determine the average GHGe per 1kcal of food typical of a diet in Austria. This benchmark was subsequently used to compare the GHGe based on the calorie density of selected foods to their actual emissions. Research indicates the daily GHGe due to food choices in Austria is approximately 7kg [DSBG]. While investigating the average daily caloric consumption for residents of Austria, discrepancies emerged. Some sources suggest an average intake of 3.700kcal [DSBG, FAO21]. However, alternative research estimates it closer to 2.100kcal [RHK17, HBDH<sup>+</sup>16]. The discrepancy stems from Eurostat data inclusion of losses through food distribution and mismanagement [Eur21]. Given these averages, the estimated GHGe per 1kcal in a typical diet in Austria is:

$$\text{GHGe\_AVG}_{1\text{kcal\_food}} = 7/2.100 = 0,00\bar{3}(\text{kg/kcal})$$

By incorporating caloric values from *FoodData Central* [USD23], we can ascertain GHGe based on the caloric content of various foods in comparison to an average diet in Austria. This methodology was applied to all in-game food items. To validate the alignment of our calculations with Carbon Rebellion's narrative, we modeled the individual's goal of achieving a 2.100kcal Nutrient-Meter. Based on our data (Table 5.2), selecting the least sustainable option, meat, five times would result in an extra 2,9 kg of GHGe.



Figure 5.9: Main scenes for the three eco-challenge quests.

Table 5.2: Table displaying the GHGe values for the food eco-challenge quest using GHGe per kg [DSBG], average energy values per food type [USD23], and the calculated value  $\text{GHGe\_AVG}_{1\text{kcal\_food}} = 0,00\bar{3}$  (kg/kcal).

	GHGe using quantity (kg)	Avg energy using quantity (kcal)	Calculated average GHGe in Austria using energy of food (kg)	Personal Difference to GHGe (kg)
Legumes 250g	0,20	250	0,83	-0,63
Meat 250g	2,25	500	1,67	0,58
Cheese 60g	0,59	240	0,80	-0,21
Vegetables 150g	0,11	45	0,15	-0,05
Rice 100g	0,37	360	1,20	-0,83

Conversely, choosing the most GHGe-efficient food, rice, six times would yield a savings of 4,98 kg GHGe relative to the average. It's pivotal to note that our GHGe metrics incorporate emissions from packaging and transportation [DSBG]. While these figures aim for transparency in the game's context rather than scientific precision, they highlight the importance of accurate data representation in the context of serious games addressing a nuanced issue like climate change [VMvB<sup>+</sup>].

**Transportation:** According to the *Federal Ministry Republic of Austria Climate Action, Environment, Energy, Mobility, Innovation, and Technology*, the cumulative distance traveled by passenger cars in 2018 was approximately  $8 * 10^{10}$  km [BMK21]. Adjusting this value for Austria's population in 2018, which stood at 8.837.707 residents, and considering daily averages, we derive a daily private car usage of 24,8 km per capita. Analogous computations for public transit (averaging bus and rail) yield a daily average of 10,54 km per capita (refer to Table 5.3). Recent data from 2022, published by the ministry, delineates the GHGe attributed to distinct transportation modalities [Umw22b]. Specifically, the mean GHGe emitted by private vehicles was quantified as 0,2176 kg GHGe/km/capita, whereas public transit, encapsulating both bus and rail, averaged 0,03935 kg GHGe/km/capita. Harnessing these coefficients and juxtaposing them with the derived distances, we ascertain the representative GHGe per km per individual for each mode of transportation:

Table 5.3: Table displaying the GHGe values for the transportation eco-challenge quest using average distance per capita per day [BMK21, Sta23], average GHGe by car or public transit [Umw22b] and the calculated value  $\text{GHGe\_AVG}_{\text{transportation}} = 0,1644(\text{kg}/\text{km})$ .

	Avg distance per capita per day (km)	Avg GHGe (kg/km)	Avg Austria's GHGe (kg/km)	Personal Difference to GHGe (kg/km)
Private Car	24,80	0,2176	0,1644	0,0532
Public Transit	10,54	0,0394	0,1644	-0,1251

$$\text{GHGe\_AVG}_{\text{transportation}} = \frac{0,2176 * 24,8 + 0,03935 * 10,54}{24,8 + 10,54} = 0,1644(\text{kg}/\text{km})$$

Using the aforementioned metrics and combining the distances to get  $24,8 + 10,54 = 35,34$  km the average citizen of Austria emits  $0,1644 * 35,34 = 5,81$  kg GHGe daily from transportation. In the context of Austria's prevalent preference for private vehicles [BMK21], a player's decision to solely use cars slightly increases their GHGe to  $0,2176 * 35,34 = 7,69$  kg, resulting in a deviation of  $7,69 - 5,81 = 1,88$  kg GHGe. Conversely, if players exclusively use public transit, emissions are only  $0,0394 * 35,34 = 1,39$  kg GHGe, leading to a savings of  $1,39 - 5,81 = -4,42$  kg GHGe. It's imperative to emphasize the intention behind these values: they are not geared towards precise scientific predictions but rather serve as data-driven estimates within the narrative's context.

**Waste management:** In the simulation, the artifact designated for waste management is a filter coffee apparatus. The reductionist methodology employed in the food and transportation sub-simulations cannot be directly transposed to the waste management simulation, due to the intricate nature of waste management infrastructure [Umw22a]. Notably, some studies have indicated that Austria's waste management operations may even confer a net reduction in greenhouse gas emissions (GHGe) [Sta22]. Therefore, for the waste management simulation, we will utilize hypothetical yet feasible values. Based on our postulation, the mean GHGe associated with a standard filter coffee apparatus over its functional life is estimated at 3kg. By elongating its utility through waste management, the emissions footprint is postulated to decrease to 1kg GHGe. Conversely, acquiring a new apparatus could amplify the emissions impact to approximately 5kg GHGe.

**Twist in the Narrative:** Systemic challenges are illustrated by events such as private jet usage, construction of new highways, and usage of coal plants. These issues have been integrated as random events during *The Twist* to contextualize individual contributions against broader systemic actions, potentially engendering feelings of disproportionality.

*The Twist* incorporates events: *Elon Musk's private jet usage*, *New highway construction to Seestadt*, and *Operational coal plants in Germany*. The precise values for these events are deemed ancillary, given their primary function is to convey thematic elements rather than influence gameplay mechanics.

**Showing communal importance:** To highlight the salience of communal efforts within the simulation, a segment has been integrated allowing participants to witness the amplification of their individual actions when scaled by Austria's aggregate populace. This inclusion is designed to elucidate the transformative potential of collective engagement in mitigating climate-related challenges. To identify a suitable visual depiction for participants, we first established the potential spectrum of impact within the simulation:

$$\begin{aligned}\text{Max Impact} &= 2.9_{\text{only meat}} + 1.9_{\text{only car}} + 1_{\text{order new}} \\ &= 5.8 \text{ kg (GHGe)}\end{aligned}$$

$$\begin{aligned}\text{Min Impact} &= -4.98_{\text{only rice}} + (-4.4)_{\text{only public transit}} + (-1)_{\text{waste management}} \\ &= -10.38 \text{ kg (GHGe)}\end{aligned}$$

Multiplying these values by the population of Austria - 8.837.707 citizens [Sta23]:

$$\begin{aligned}\text{Worst Case} &= 8.837.707 \times 5.8 &= 51.258.700.6 \text{ kg} \\ &= 51.258.7006 \text{ t (GHGe)}\end{aligned}$$

$$\begin{aligned}\text{Best Case} &= 8.837.707 \times -10.38 &= -91.735.398.66 \text{ kg} \\ &= -91.735.39866 \text{ t (GHGe)}\end{aligned}$$

The selected visualization encompasses a range from approximately -90.000 to +50.000 tons of GHGe. For clarity and relevance, we opted to express this in terms of *GHGe offset by a single windmill*. By employing the *Greenhouse Gases Equivalent Calculator* from the *United States Environment Protection Agency* [US 15], it's deduced that, at the upper limit, 91.735 tons of GHGe equates to the offset potential of approximately  $91.735, 39866 / 3.596 = 25, 51$  windmills. Conversely, at the lower threshold, 51.258 tons of GHGe can be offset by about  $51.258, 7006 / 3.596 = 14, 25$  windmills.



Figure 5.10: *The Twist* in the narrative.

**Call to Action:** We incorporated the element of "speculative design," which entailed envisioning various future scenarios as potential solutions [SPD21]. Therefore, the concluding segment termed the "*Call to Action*", invites participants to introspect on their allegiance to systemic climate initiatives. Furthermore, we aimed to present plausible strategies that individuals can adopt within their societal spheres. Three actions selected for this segment were: *Promote reduced meat consumption among peers*, *Support a climate-conscious political party*, and *Facilitate a community-based climate policy rally*. Mirroring the challenges in *The Twist*, quantifying the real-world repercussions of these collective endeavors remained elusive. The exact values for these events are considered secondary since their main purpose is to communicate thematic elements.

## Game Development

The narrative's name, "Carbon Rebellion companion," draws inspiration from the Extinction Rebellion movement by promoting environmental awareness and individual responsibility<sup>9</sup>. We chose the *Godot Game Engine version 4.0* [God14] for the development of the narrative. Godot's straightforwardness and lightweight design [Tho20], combined with a robust editor, matched our work's scope better. All 3D assets for Carbon Rebellion were procured from *Poly Pizza* [pol21], known for its vast array of low-polygon 3D materials. The platform's provision of *.glb* download files, which are Godot-compatible, streamlined our process. During the game's development, we imported some assets into *Blender* [Ble02] for customization. For instance, we modified a street sign asset to bear the name *Carbonia*, a sign to the narrative's fictional setting. We incorporated sound assets from *OpenGameArt* [Ope09], especially for interactive cues like clicks and event-related sounds. Each sound was meticulously chosen and tailored to resonate with the narrative's ambiance. For ambient music across diverse scenes, we opted for AI-generated, royalty-free tracks from *Beatoven.ai* [bea22]. To mirror the tone and theme of specific scenes, we employed various modifiers in the web application, such as *Exciting*, *Dramatic*, and *Epic*, ensuring a deeper player engagement.

The *Singleton Pattern* [GHJV09], often viewed critically in some contexts, emerged as a favored approach in game design, particularly within the Godot engine framework [God23]. This was especially handy for global management entities, like our *SoundManager*, which oversees in-game audio. Additionally, the observer pattern [GHJV09] was applied through the inbuilt *Signals* API, fostering modular design by enabling components to interact and respond to each other without tight interdependencies. In alignment with the game's core components, individual scenes with related *.gd* scripts were crafted. These scripts encapsulate game mechanics, physics computations, and event dynamics. Every eco-challenge quest stands as an independent 2D scene, equipped with distinct scripts and sub-scenes. For primary scenes (Figure 5.8) and *The Twist* segment (Figure 5.10), dedicated 3D scenes were formulated, with scripts managing scene shifts and the portrayal of various game components.

<sup>9</sup><https://rebellion.global/> – Accessed Dec 2024

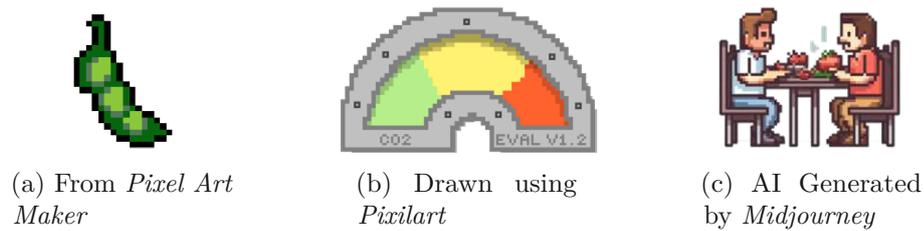


Figure 5.11: Examples of 2D assets created using AI tools.

### 5.2.3 User Study

The research utilized a qualitative methodology, conducting interviews to collect in-depth data. Semi-structured interviews were crafted with foundational questions to guide the discussion. However, they were flexible enough to adapt to each participant's views and experiences. The primary metric of interest was motivation, with an emphasis on assessing intrinsic motivation related to climate-centric actions. The interview began with an exploratory query, requesting participants to elucidate their interpretation of the game's primary objectives. This was typically succeeded by a structured probe: *If asked to encapsulate this game in a concise summary of 1-2 sentences for a peer, how would you articulate it?* Such open-ended questions were designed to capture organic participant feedback and to facilitate the trajectory of the conversation based on their individual areas of interest. The structured segment of the interview incorporated targeted queries addressing: (1) the emotional resonance invoked by the game, (2) the game's influence on their climate change motivation, (3) the drive for climate action, and (4) potential areas for game enhancement. To ensure rigorous data capture, interviews were audio recorded using a smartphone application, enabling the moderator to maintain undivided attention to participant responses. Concurrently, observational data on participants' facial expressions were meticulously noted, serving as a supplementary metric to ascertain emotional engagement during gameplay and the interview.



(a) Home Screen

(b) Zoom Out for the Twist

Figure 5.12: Main Game and Zoom Out views.

**Pilot Study:** We conducted four smaller-scale pilot sessions via online meeting platforms, each lasting about 60 minutes. These sessions included extensive interviews and provided opportunities for participants to give feedback. Notes were taken on technical issues, player reactions, and thought processes during gameplay of Carbon Rebellion. We faced challenges such as compatibility issues with outdated computer hardware and the unreadability of text on 4K monitors, which highlighted the need for a controlled study environment to ensure consistency and reduce complications. Based on the feedback received, several important changes were made to improve the game. These adjustments focused on enhancing visual clarity and refining the game's flow and timing. Feedback indicated that textual explanations of game controls were inadequate; we responded by adding on-screen legends to make controls clearer. After careful consideration and the insights gained from these pilot studies, we decided to conduct future studies in person at the institute. This move to a controlled environment aimed to minimize the complications associated with online setups and capture participants' emotions and reactions more effectively through face-to-face interactions.

**Participants:** Participants were recruited from courses offered by our lab at the university and through word of mouth. Those interested in participating in the user study were encouraged to join. We recruited 21 participants primarily through email invitations. The majority were male ( $N = 15$ ), followed by females ( $N = 4$ ) and non-binary ( $N = 2$ ). Out of a total of 21 participants, 14 were between the ages of 25 and 34, while the remaining 7 fell into the 18 to 24 age group. The majority were undergraduate students ( $N=12$ ), although there were a few exceptions, including some at the master's levels ( $N=3$ ). Among the 21 participants, 6 were staff members. Given that the participants were primarily recruited from an academic setting, the demographic makeup displayed notable uniformity and held a left-leaning political inclination. While no financial compensation was provided, students received two bonus course points for participating and submitting a one-page report on the study. Staff members and others not enrolled in the courses also joined, motivated by their interest in the topic of the study.

**Procedure:** Participants were provided with a computer, mouse, keyboard, and a display equipped with speakers. They sat in front of the display while a moderator, equipped with a laptop, was positioned nearby to facilitate the session and monitor interactions. Participants were provided with a verbal overview of the study's context and instructions on how to engage with the narrative. They were presented with an informed consent form, which they reviewed and signed. This stage also allowed for any questions the participants might have regarding the study's procedure. Following the completion of the consent form, participants proceeded to engage with the game as shown in Figure 5.12. The gameplay lasted approximately 20 minutes per participant. During the gameplay session, participants were encouraged to think out loud, verbalize their thoughts and fully express what was going through their minds and their thought processes. The moderator documented these insights manually as no audio or video recordings were taken during the gameplay. Upon the conclusion of gameplay, we conducted a semi-structured interview,

which we audio-recorded for subsequent in-depth analysis. Participants were offered a choice between two languages for the interviews to ensure their comfort in expressing their opinions. They were asked about their emotional responses to the game, its impact on their motivation regarding climate change, and suggestions for game improvement. The entire user study lasted approximately 50 minutes to one hour.

#### 5.2.4 Results

**General observations:** *Participants exhibited significant autonomy: even when confronted with initial challenges related to game mechanics, the majority adeptly navigated to solutions without external facilitation [This finding contributes to Chapter 7, subsection 7.3: User Autonomy and Control.]* Additionally, a consistent reaction was observed in response to *The Twist*, specifically the text *Elon Musk entered their private jet. Every participant uniformly manifested either a muted chuckle or a smile. Humor played a role in engaging and amusing people, rendering them more open to the content presented [This finding contributes to Chapter 7, subsection 7.3: Collaborative and Relational Design.]* This ubiquity of response suggests that this narrative element held a salient resonance, potentially attributed to its humorous undertone, the unexpected nature of the content, or its reflection on contemporary societal discussions. The unexpected plot twist diverged from the participants' initial expectations, eliciting surprise and intrigue, which in turn enhanced their engagement with the narrative. Such spontaneous and uniform emotional feedback highlights a profound level of engagement and immersion among the participants, indicating that select components of the narrative were notably efficacious in eliciting authentic emotional responses. *Participants predominantly selected the environmentally friendly options when faced with decisions in the game [This finding contributes to Chapter 7, subsection 7.3: Personalization and Adaptability.]* This trend can be attributed to several factors, notably the design of the Carbon Rebellion companion, which nudges players toward environmentally friendly choices, and the question of whether participants are reflecting on their real-life decisions or are fully immersed in the game's universe, making choices based on the narrative context.

**Interview data:** We extracted five predominant themes. To analyze the data, two researchers with expertise in HCI collaborated and coded the raw data [BC19]. We adopted a constructionist approach within reflexive thematic analysis to investigate how participants construct meaning related to climate change through the narrative and discourse, emphasizing the context-dependent nature of climate-related knowledge [BC21]. Researchers familiarized themselves with the content, identifying patterns and features inherent within the data, and subsequently coding these findings. These preliminary codes were organized into potential themes keeping research objectives in mind. Throughout this process, both researchers continually reflected on the overarching goals of the study, thereby constructing a comprehensive understanding of the themes that emerged during the analysis. The Miro online whiteboard tool was employed to foster a collaborative environment for data visualization and thematic categorization. We used the tool to

structure and compartmentalize insights derived from the recorded interviews. This subsequently facilitated rigorous discourse between the researchers, aiding in the formation of the five key themes:

1. ***Narrative's Message Through the Eyes of Participants:*** When asked about their initial impressions and what they consider to be its key message, most responses aligned with our intended message. One participant stated that "*[The narrative is] more about putting your contributions in terms of decisions you make and their impact, putting that into perspective next to some of the more, let's call them more serious or more significant, choices or decisions or policies that could be affecting the environment more*". Another participant's takeaway was "*that collective action is more useful than individual contributions*". Meanwhile, others provided more abstract reflections on the nature of climate change and the need for personal growth to address this global issue: "*[My main takeaway from the narrative is] that you often have to move out of your comfort zone or spend time so that you can do something about climate change.*" During the interviews, several noteworthy responses perfectly encapsulated our intentions when we designed the game. For example, one participant summarized their main takeaway as follows: "*[My main takeaway is] that we individually already have an impact to make on the environment, and if we make conscious decisions about what we buy, how we buy - so "reuse, reduce, recycle" and so on - those core values are environmental issues that we can actually work on. We already make an impact in our local environment, but if that's something that more people do, it becomes something that is measurable - even by global standards.*"
2. ***Attitude towards climate change:*** Most participants had a pessimistic tendency for example "*.. that the impact of an individual is definitely worth something, but if we don't do something globally or politically, [the individual efforts] won't help much.*" Another participant brought up the point that "*No matter what you are doing, the system behind everything is much bigger*". Similarly, another participant said that "*even if everyone in continent became green fanatics, as long as the politicians don't change, nothing big is going to happen*". One participant commented on the current situation of attitude, they thought "*we are divided, but a big part of society still thinks that no matter what we do, if big corporations or big countries don't reduce their [impact] - then it's all for nothing. There is definitely a pessimistic tendency.*" Another participant attests to this pessimistic tendency: "*I don't believe - you showed this in the game with the bars - [that you can do much as an individual]: How much is ultimately done by countries, companies and the super-rich?*". Many participants expressed a sense of climate anxiety, believing that individual efforts may have limited impact without global or political action. They emphasized the significance of systemic changes, collective actions, and the influence of politicians and corporations, contributing to a prevailing pessimistic outlook on addressing climate issues. Most participants reported that the narrative did not discourage them from climate actions. This effect could be attributed to our

approach of offering individual options for collective action and illustrating their impact when the entire population of Austria engages in environmentally friendly actions. We found it surprising that the participants did not feel discouraged in the slightest by the narrative. Many expressed the belief that the game would not demotivate anyone. It's possible that their preexisting awareness of a bleak future insulated them from being disheartened by the narrative's unexpected turn. As one participant put it: *"When Elon Musk flies around the earth 3 times in his private jet or flies to the moon or Mars for fun - but also various productions in China or America with their 'broom broom' unfiltered cars - these things add up to a whole different level. We can take the train as much as we want or buy no meat or only certified organic meat - it doesn't matter."*

- 3. *Realization of agency:*** We discerned a salient positive influence exerted by the narrative, particularly on participants who initially harbored the belief that their individual actions bore minimal significance. These individuals came to acknowledge that while isolated personal efforts may appear inconsequential, collective action possesses the potential to effect meaningful change. This realization was articulated by one participant who remarked: *"In my opinion, climate change was more caused by coal plants, non-renewable energy, and the lack of or inadequately stringent regulations for factories. While these factors represent the foremost threats, I consistently underestimated the impact of an ordinary person's contributions. This insight from the game resonated with me: I may not control the actions of manufacturing businesses—what I do may seemingly hold little sway—but [the narrative] illuminated the fact that when numerous individuals engage in concerted efforts, they can collectively combat climate change and effect a tangible difference."* We arrive at the inference that Carbon Rebellion not only offers a broader perspective but also highlights avenues for individual agency. Another participant rationalized this by asserting: *"Typically, we do not concern ourselves with our [community] CO<sub>2</sub> emissions, as we tend to fixate on our personal impact, which, in isolation, appears inconsequential. Yet, when one calculates this cumulative impact across an entire population, the results can be staggering."* Another participant appreciated that the narrative conveyed the message that *"one person alone cannot effect significant change, but when everyone collaborates, meaningful transformation becomes attainable."* At the same time, participants recognized the limitations of individual agency, acknowledging that personal sacrifices alone might not significantly impact the environment. One participant shared the following: *"[The game is about] expanding people's awareness that it's not so easy in our world and that we should be looking at how we behave right now, because I think climate change is very real and affects us all and especially our successors at some point, and we should definitely do something. [the explicit question of how we should act] As already indicated in the game, very much through small actions of our own and also as indicated in the game, we can only have a certain degree of influence on whether we now buy certain things or consume less electricity. Where action needs to be taken, in my opinion, are the big companies that are doing a lot of damage to the environment."* Another

participant argued *"me suffering in 32°C will do nothing for the environment"*.

4. ***Fostering critical thinking:*** Participants consistently emphasized that the narrative's impact lay more in the discussions it sparked than in the gameplay itself. One participant remarked *"More significant impact came from the questions than the game itself because the game is entertaining, and individuals may readily engage in actions [within the narrative] that are considered bothersome in real-life scenarios. However, the discussion, especially those related to political matters [..discussion truncated..], can serve as instructive tools."* This recurring theme consistently surfaced when participants were asked about the impact of the narrative. We posit that a contributory factor to this phenomenon is the awareness of the subject matter among the participants. For instance, one participant said *"The content may be somewhat protracted, yet it serves as a catalyst for contemplation - I found it acceptable."* Another discernible indicator validating our hypothesis that the narrative indeed fosters critical thinking and ignites thoughtful discussions is the extensive array of topics. The topics broached encompassed a wide spectrum, including nuclear power, solar energy, politics, optimism, pessimism, and philosophy, among others. These dynamic exchanges served as compelling evidence of Carbon Rebellion's ability to facilitate substantial discussions among individuals, encompassing diverse facets of climate change and its broader ramifications on society, politics, and personal convictions.
  
5. ***Climate change is a complex issue:*** Participants highlighted the importance of personal responsibility, the unequal distribution of climate impacts, and the role of individual actions in addressing climate change. One participant emphasized the absence of a universal solution due to the multifaceted nature of climate change, stating, *"There is no one-size-fits-all solution for climate change."* A specific challenge associated with climate change is the disparity between responsibility and impact: industrialized nations often contribute significantly more to greenhouse gas emissions compared to developing countries, yet it is the developing countries that frequently bear the brunt of the consequences [Nyi21]. This disparity, coupled with the political tendency to favor short-term solutions for long-term problems, has sparked a debate on climate change during the interview. One participant noted that *"It is when you deal with climate change on a personal level and try to reduce certain things that you get particularly annoyed or angry when someone flies around in a private jet"*. They highlighted the political nature of climate discussions and the need to consider diverse perspectives while emphasizing both personal and systemic actions as vital components in tackling this multifaceted challenge. A participant highlighted, *"Even if the system is much bigger than you, it still matters what you do because if everyone does it, it has an impact. Both sides [of climate change] are shown [in the narrative], not just one side or the other. People often focus on the fact that you only have to take care of your own impact or the other way around, that people think it doesn't matter if you eat meat every day because the system is the only really important thing - both sides are shown [in*

*the narrative].*" *The game's inherently political nature also renders it controversial, as one participant commented: "[The game] was very political for me. Playing a game is never going to change my political opinion, especially with the recent disappointments in politicians... because of the general disappointment - I associated some of the questions directly with a negative sentiment" [This finding contributes to Chapter 7, subsection 7.3: Personalization and Adaptability.]* Based on these responses, we believe that we have effectively illustrated the complexities of climate change without suggesting simple solutions. *Many participants appreciated the narrative's nuanced approach, avoiding "greenwashing" and addressing the broader global context [This finding contributes to Chapter 7, subsection 7.3: Cognitive and Emotional Support.]* One participant was even surprised and mentioned that they appreciated not being *Greenwashed*, noting, *"I thought [the narrative] would just end like this, the game says "Okay, you're in the green, everything well done, you are great", but then the zooming out happened [to the global events] which I did not expect but thought it was good."*

### 5.2.5 Discussion

"Carbon Rebellion Companion" stands as a compelling proof-of-concept, illustrating the viability of presenting diverse perspectives on climate change without disheartening individuals. This interactive narrative platform delivers digestible chunks of information within an engaging format, effectively rendering complex climate issues accessible and enjoyable for exploration. Distinguished from the array of serious games tailored for climate change education, which adopt various approaches – from simulation and modeling to decision-making and storytelling – "Carbon Rebellion" amalgamates elements of both, offering individuals a multifaceted experience. While games like "Fate of the World" have been criticized for invoking feelings of despair [Red11], our narrative empowers players to enact environmental reforms, showcasing the potential of collective effort. Our study findings highlight the capacity of interactive narrative media to raise awareness, foster critical thinking, and reshape perceptions concerning critical global issues like climate change. Echoing previous research [Dah14, NAO<sup>SM</sup>+17], our results emphasize the transformative potential of narrative, particularly in shaping participants' attitudes, particularly helpful in conveying scientific information to non-experts. Through our study, we observed a shift from pessimism to newfound positivity and empowerment at the community level, signifying the evolution of participants' understanding of climate change during their engagement with the narrative.

Moreover, the narrative not only informs but also has the potential to influence societal discussions, as evidenced by participants' reactions to contemporary references. During our observational phase, we noted consistent positive reactions, such as muted chuckles or smiles, indicating a notable resonance with this narrative element. This resonance may be attributed to elements of humor, unexpectedness, or its reflection on ongoing societal debates. Participants also demonstrated significant autonomy as they navigated the narrative's challenges, reflecting a high level of engagement crucial for the success

of any interactive medium aiming to raise awareness about complex issues. Traditional campaigns may convey similar messages but lack the personalized, experiential aspect of gameplay.

The interview data further enriched our understanding of participants' experiences, revealing recurring discussions around the complexity of climate change and the absence of a universal solution. Participants expressed frustration over the unequal distribution of climate change impacts, especially when contrasted with displays of excess, such as private jet travel. This tension between individual actions and systemic issues highlighted the complex nature of climate change discussions. Our narrative's effectiveness in communicating these complex topics aligns with previous research [KN19, SB18], acknowledging the narrative's potential to engage and inform audiences effectively. This power can be harnessed for other social causes, evoking emotions and motivating people. Whether through interactive media or broader storytelling, the narrative serves as a potent tool to raise environmental awareness, encourage critical thinking, reshape perceptions, and ultimately influence behaviors. This warrants a more comprehensive and systematic inquiry.

"Carbon Rebellion" places a strong emphasis on personal agency and collective action, demonstrating to players that their choices matter. Many participants, initially feeling their individual actions were inconsequential, experienced a paradigm shift, realizing that collective efforts can lead to meaningful change. This underscores the narrative's potential to shift perceptions and attitudes, not just inform. Furthermore, the narrative's ability to foster critical thinking was evident, with some participants finding the narrative's questions more impactful than the gameplay itself. This suggests that while entertainment is crucial, the narrative's educative and reflective components play an equally, if not more, vital role in influencing participants. This approach extends beyond mere information dissemination; it has the potential to reshape perceptions and attitudes toward a wide range of societal challenges. We aimed to leverage data as a capacity to empower players to make informed decisions and strike the balance between understanding sustainability deeply and taking impactful real-world actions [LTR<sup>+</sup>23]. To address the research questions posed in the introduction and to re-emphasize our findings:

- **RQ1:** Developing an engaging climate change narrative rooted in factual data involves providing individuals with diverse perspectives from various stakeholders. It's essential to present an honest portrayal of the severity of climate change alongside actionable strategies to promote individual involvement. Highlighting the strength of community-based efforts in addressing this global issue is also crucial.
- **RQ2:** The narrative demonstrated the interplay between the personal narrative and the data-driven narrative through the design of gameplay that contrasts individual actions with systemic issues. This is highlighted in the game through various mechanisms like the personal decisions in mini-games and the systemic events known as *The Twist* where the larger, uncontrollable factors are introduced, such as the use of private jets or construction of new highways. We conclude that

individual experiences and preferences, when combined with data-driven narratives, can significantly impact user engagement. Some felt that the narrative was about understanding the impact of personal decisions in the broader context of more significant choices or policies affecting the environment. Others believed that collective action is more beneficial than individual contributions. Such personal reflections, combined with the overarching narrative, can foster deeper engagement and understanding of the subject matter. For example, an intriguing observation from all participants was their reaction to *The Twist*, as each invariably responded with a slight audible laugh or smile at this moment.

- **RQ3:** Interaction with a data-driven narrative can foster critical thinking, evoke emotional responses, and promote a drive for climate action. While many participants had a pessimistic tendency regarding the impact of individual actions, the narrative did not discourage them from climate actions. Instead, it emphasized the importance of collective efforts and policy measures in making a significant difference, cultivating a sense of hope and agency in their actions. The narrative's focus on emotions and subversion led to lively discussions and promoted critical thinking. Notable trends and tendencies were observed, such as (1) the climate action categories "More Tax" and "Renewables" delivering consistent messages, and (2) every participant opting for environmentally friendly choices.

**Limitation and Future Work:** The participant group was relatively homogeneous leading to a convergence of opinions. One participant said *"..because this is a topic that is talked about all the time anyway and I think that most people have already formed an opinion. Either they care more or less, but half an hour won't change their minds now."* Some participants believed that the narrative's scenarios were not particularly challenging, with the main issue of the absence of meaningful consequences for their actions within the narrative. A participant stated *"I think it's not about difficulty because difficulty is cool in a game, but it's about making you feel a bit bad [...] the first thing that comes to mind: there are lots of games like this, I see them advertising like 'You need to keep the house warm; otherwise, the king will be frozen,' and it makes you feel a bit bad. If you do something like, buy more meat, and then it shows something like 'the fabric is growing,' something that makes you feel the consequences. Not more challenging, because challenging makes you feel good. If you make the game more challenging, I don't think you will reach your goal; you need to make the game more empathetic - something to increase the empathetic aspect. Not only showing that the number is going up or down but being overly dramatic - and don't do it exactly this - in the supermarket game when buying too much meat, you could show a dead cow on the screen which makes you feel bad."* They emphasized the importance of evoking empathy and making individuals feel the real-life consequences of their decisions. For future steps, the narrative's challenges present individuals with morally complex dilemmas that are both difficult and thought-provoking. These dilemmas should not be designed to test the player's gaming skills or reflexes but rather their ethical judgment and decision-making abilities. To achieve this, game developers should craft scenarios that force individuals to consider the broader

implications of their decisions within the context of environmental responsibility. The challenges should encourage individuals to grapple with questions like whether personal convenience should outweigh ecological concerns, or whether short-term gains should take precedence over long-term environmental impacts. Some participants found the puzzle in the narrative to be straightforward and didn't see a reason not to solve it, stating, *"Why would I not solve the puzzle? It's a game - I see a puzzle, I solve the puzzle."* Developers can incorporate intricate clues, requiring individuals to think critically and use their problem-solving skills more extensively. Puzzles can, in turn, exert a tangible influence on the narrative, or the overarching storyline, instilling within individuals a profound sense of agency and accountability. Furthermore, additional studies should be conducted with a wider range of participant demographics, especially regarding their awareness of climate change. This should involve inviting participants from various age groups, and different social and academic backgrounds. Additionally, collecting responses from climate deniers is an interesting aspect of future research to explore the narrative's impact on individuals with varying perspectives on climate-related matters.

### 5.2.6 Conclusion

The challenge of climate change communication is to inform, engage, and inspire action effectively. To address this, "Carbon Rebellion Companion" was designed with a narrative that not only informs but also resonates deeply with its audience. By addressing relatable challenges, the narrative fosters a sense of agency, shapes attitudes, and promotes critical thinking about climate change. The narrative of "Carbon Rebellion" flows from a data-driven foundation through engaging tasks and unexpected twists, to a final call to action, all designed to highlight the broader community impact of individual and collective decisions. The integration of AI tools in the development process not only facilitated the creation of scenes but also enabled rapid prototyping, fostering discussions and timely changes within the scenes. The findings from the study highlighted the effectiveness of such a holistic approach in climate change communication. The pessimistic tendencies observed among participants highlighted the urgency of the situation, yet the narrative's emphasis on collective strength offered them hope. In post-gameplay semi-structured interviews, participants discussed a variety of climate change-related topics, reflecting on the personal and broader systemic impacts of their decisions. This highlights the game's role in sparking thoughtful and critical discussions, with responses that extended beyond the game's content to broader environmental and societal concerns. Such engagement indicates that the game effectively deepens participants' involvement with climate action and has the potential to shift perspectives, promoting a more reflective approach to climate change and personal responsibility. In navigating the complexities of climate change, narratives like "Carbon Rebellion" play a crucial role in guiding and inspiring community involvement. Through the power of a factual narrative, the game fosters a renewed sense of agency and collective purpose in addressing one of our time's most pressing challenges.



# Mindful Box Companion

This chapter introduces a tangible opt-out solution, the reactive Mindful Box companion, designed to promote mindful smartphone use and reduce screen time. It is based on our following publication:

## Publication

Shahu, A., Sehic, E., Michahelles, F. (2025). Digital Detox by Design: Evaluating a Lockable Box for Mindful Technology Use, Designing for Self-Determined Engagement with Pervasive Technology, IEEE Pervasive Computing special issue (Submitted - Under Review)

The advent of technological innovations such as computers and smartphones has profoundly changed the way people interact socially. However, this constant connectivity has led to excessive smartphone use [FKHM<sup>+</sup>21], which has been shown to have detrimental effects on both physical and mental health [DAA15, YCHS21]. This is largely due to mindless and unhealthy patterns of phone use, characterized by aimless scrolling and unfocused interactions [Lup21]. Previous studies have suggested various strategies to counteract digital overuse [For15, WOE19, SMWM22], including maintaining a healthy lifestyle, eliminating negative digital content, and engaging in physical activities such as walking and yoga. While applications to support digital detox are emerging, none have gained significant popularity. Despite the availability of such applications, screen time has continued to increase <sup>1</sup>. Adaptive digital solutions in which users retain agency, such as MyTime [HHKK16], may fail because compulsive behaviors are often triggered by the mere presence of a smartphone [Lup21, TFRR14]. Researchers have used abstinence tasks to assess the addictive nature of smartphones and have found that users experience anxiety and subsequent relief during such tasks [WOE19, Syv20].

<sup>1</sup><https://www.washingtonpost.com/business/2019/06/21/screen-time-is-rising-reading-is-falling-its-not-young-peoples-fault/>

The challenge remains to develop methods that effectively utilize physical opt-out while mitigating its negative effects. Our research focuses on the design of a tangible physical opt-out solution to promote intentional and mindful device use, with the goal of reducing screen time while maintaining user agency. Through expert interviews with therapists working in the field of addiction, we found that digital device free hours or days, along with digital device vacations, hold promise as effective interventions. It is important to note, however, that complete physical disengagement could also inadvertently exacerbate digital stress and loss of agency. We developed a "mindful box" with a locking mechanism controlled by a microcontroller and solenoid lock, allowing users to set timers and securely store their devices (phones and tablets) in the custom-designed wooden case. In addition to the locking function, the prototype included features such as gentle wake-up functions, meditation support, a cheer list for motivation, and water reminders to promote wellness. During a one-week field study with seven participants, we evaluated the effectiveness of our box. Participants were asked to keep daily diaries to record their experiences and interactions with the Mindful Box. Interviews provided deeper insights into subjective experiences and interpretations of the prototype's features.

Analysis of our results showed that the Mindful Box, particularly its locking feature, had a significant impact on reducing average screen time. The Wilcoxon signed-rank test comparing the average screen time before and after the study showed a statistically significant difference with a corresponding p-value of 0.016. Users praised its ease of use and effectiveness in combating distractions, promoting mindful use, and highlighting its potential as an effective means of limiting digital device use. However, some users found the lock feature inconvenient, requiring adjustments to their routines and planning ahead. It proved beneficial for certain tasks and users, highlighting the importance of personalized optimization for different needs and work styles. Our work highlights the need to find the right balance between digital devices and personal well-being. The mindful box is a promising intervention with a high predisposition for absent-minded use, empowering users to regain control over their digital habits while preserving their autonomy. Autonomy was supported by allowing users to set their own lockout durations and disengagement timing, reinforcing a sense of control rather than restriction. Competence was addressed through repeated habit-forming interactions and goal clarity, which participants found empowering. Although less explicitly social, the intervention supported relatedness by encouraging more present interactions, as some participants locked their phones during social gatherings to be more engaged in the moment.

### 6.1 Related Work

Modern mobile technologies are intentionally designed to be engaging because of the attention economy [HS20, Hog01]. The ease of use of smartphones makes it effortless for individuals to spend an inordinate amount of time engaged without even realizing it. Absent-minded use occurs when users engage with their phones without a conscious intention or goal, often resulting in more time spent on their phones than they desire [MDROS18]. Many smartphone users have reported excessive and habitual use of

technology that they later regret or find meaningless [Lup21]. Persuasive technologies in digital environments can influence user behavior without coercion [Fog02]. Some users move applications to secondary screens to reduce distractions and curb excessive smartphone use [Syv20]. Major companies have introduced digital wellbeing approaches such as Google Wellbeing and Apple Screen Time. Wellbeing apps in app stores offer features such as blockers, timers, and motivational tools [MRDR19]. Khot et al. [KYA22] aimed to promote positive wellbeing by encouraging regular micro-breaks from screen work through Zenscape, an innovative tangible system inspired by Zen garden philosophy that provides non-work related creative micro-activities through the action of agitating water and sound. Paradoxically, some of these wellbeing applications address problems caused by the very phones on which they are installed, as the mere presence of a phone can be disruptive [TFRR14].

Dumbphones<sup>2</sup> represent an approach to mindful phone use because they offer only basic functions such as calling and aim to separate the pragmatic aspects of smartphones from their hedonic qualities. By reducing the hedonic qualities, dumbphones aim to diminish the emotional appeal of smartphones. In addition, groups have organized an annual national (and global) <sup>3</sup> Day of Unplugging, which has been held for several years and has a large following. Similarly, travel companies promote so-called digital detox camps or centers and "mobile-free" vacations, all designed to help people escape from everyday digital connectivity. Studies have shown that on-device digital opt-out methods are not very effective in curbing excessive use [THG<sup>+</sup>22]. Physical opt-out strategies, an under-researched approach, involve the conscious management of smartphone use. Separating users from their phones can cause anxiety because phones are perceived as extensions of themselves [WOE19]. Removing phones completely or forcing users to turn them off and keep them out of sight also increases anxiety [CRCC14]. Approaches such as phone sleeping bags <sup>4</sup> and Yondr Pouches<sup>5</sup>, which block phone signals, create phone-free spaces to encourage face-to-face social interaction. However, such strategies can limit user agency and lead to a sense of missing out. Our approach to physical opt-out involves implementing a temporary physical barrier using an "out of sight, out of mind" strategy. This allows users to intentionally lock their devices and prioritize wellness before gaining access to their phones. We prioritize user agency by giving them the flexibility to choose the duration of the device lock and the specific time they want to activate it. This allows users to plan alternative activities during the time they are intentionally away from their devices.

## 6.2 The Mindful Box Companion

The concept of the Mindful Box was based on themes that emerged consistently in previous studies, particularly Nudgit and Watchful Detox Companion, and in preliminary

<sup>2</sup><https://t3n.de/news/dumbphones-handys-simpel-801028/>

<sup>3</sup><https://www.unplugcollaborative.org/>

<sup>4</sup><https://unplugrevolution.com/product/phone-sleeping-bag/>

<sup>5</sup><https://www.veryondr.com/>

research. Nudgit addressed this by embedding subtle nudges into content consumption, while Watchful Detox focused on self-monitoring through wearable feedback to increase awareness. However, findings from both studies also suggested that awareness alone was often not enough, users often expressed a desire for stronger mechanisms to resist temptation and enforce breaks. The Mindful Box was designed in direct response to this need: a more tangible, reactive intervention that externalizes control and gives users a way to intentionally place their device out of reach. Initial problem identification emerged from recurring themes in expert interviews and preliminary surveys; to translate these insights into concrete design directions, we conducted iterative ideation workshops with fellow researchers, where low-fidelity mockups and speculative concepts were critiqued and refined. Throughout this process, we experimented with different levels of user control and lock duration feedback.

### 6.2.1 Preliminary Research

To gain a nuanced understanding of the problem space, we began our research with an online survey that explored participants' attitudes toward digital device use and its potential link to digital addiction. The survey explored usage patterns, daily screen time, related challenges, and experiences with digital detox. A total of 118 individuals participated, primarily in the 24-27 age range, with a gender distribution of 51.7% male and 45.8% female. Notably, 41.5% reported owning four or more digital devices, and functionality was the primary motivation for purchasing new devices (39.8%). More than half (55.9%) of respondents used their smartphone more than five hours a day. The most commonly used apps were communication ( $n = 104$ ) and social media ( $n = 96$ ), followed by music and video ( $n = 85$ ) and productivity tools ( $n = 81$ ), while photography ( $n = 44$ ) and games ( $n = 37$ ) were less commonly used. Within the 24-27 age group, communication and social media dominated digital activities, with web browsers (34.5%) and WhatsApp (16.1%) being the most popular platforms. Interestingly, 60.2% of participants reported health issues related to device use, including physical symptoms such as eye strain and headaches, and psychological effects such as lack of concentration and focus. In terms of digital detox, 62.7% ( $N = 74$ ) had previously attempted to take a break from devices - typically no longer than a month - with many using app blockers to assist. Additional comments revealed concerns about unconscious content consumption and the difficulty of changing ingrained habits, highlighting the need for interventions that promote more mindful digital use.

To supplement the survey results, we conducted expert interviews with individuals specializing in clinical and health psychology and psychotherapy with a focus on digital addiction. Each session lasted approximately 30-35 minutes and was thematically analyzed using a Miro board. The interviews explored key topics such as the definition and benefits of digital detox, the challenges people face in attempting detox, and strategies for overcoming them. Experts highlighted the importance of setting clear goals and boundaries, and emphasized mindfulness and self-reflection as critical elements in the detox process. Thematic analysis revealed five central themes: "therapy," "digital addiction,"

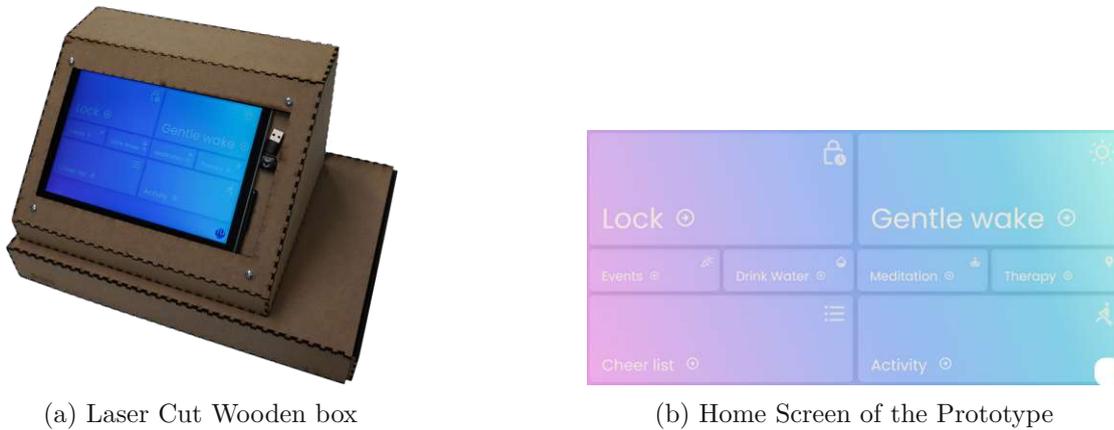


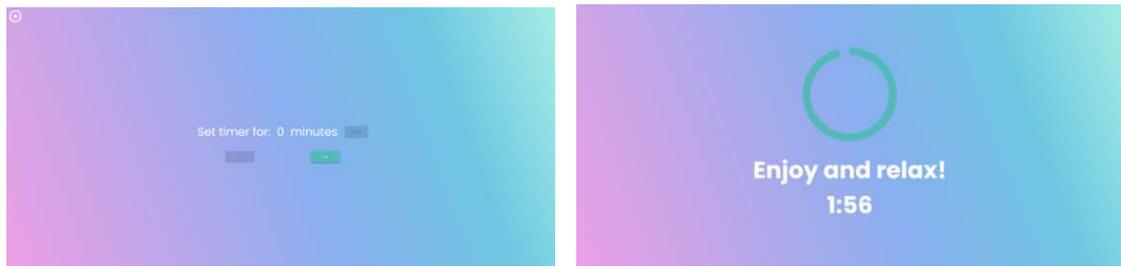
Figure 6.1: Laser-cut wooden box containing a Windows tablet, microcontroller, and solenoid locks, with the tablet serving as the host for the prototype application.

"what leads to problematic use," "consequences of problematic use," and "characteristics." In the area of therapy, the need for self-regulation and intrinsic motivation was emphasized, along with a non-critical, open-minded approach to behavior change. Social pressure, self-doubt, and societal norms were identified as key contributors to addictive behavior. The consequences of problematic use were seen to extend beyond individual health, affecting personal relationships, emotional well-being, and daily functioning. Based on these findings, the experts recommended that any digital detox companion should include features such as physical boundaries, alternative offline activities, performance incentives, and tools for reflection and mood tracking - with the ultimate goal of reducing digital dependence in a supportive manner.

### 6.2.2 Box Design

Based on findings from preliminary work and existing literature, we created a digital detox companion called the Mindful Box (MBox), as shown in Figure 6.1a. Three researchers synthesized the data and conducted a collaborative brainstorming session to finalize the following eight features presented on the home screen.

- **Home Screen:** The home screen prominently displayed all features, as shown in Figure 6.1b. The core features, Lock and Gentle Wake, were highlighted with larger fonts to emphasize their importance.
- **Locker:** This feature allows users to lock their smartphone or tablet away for a selected period of time. Users have the freedom to customize the duration of the lock by setting a timer for the periods of time they wish to store their devices. Once the timer was set, they were instructed to place their devices in a drawer and securely close it before clicking the lock button, as shown in figures 6.2a,

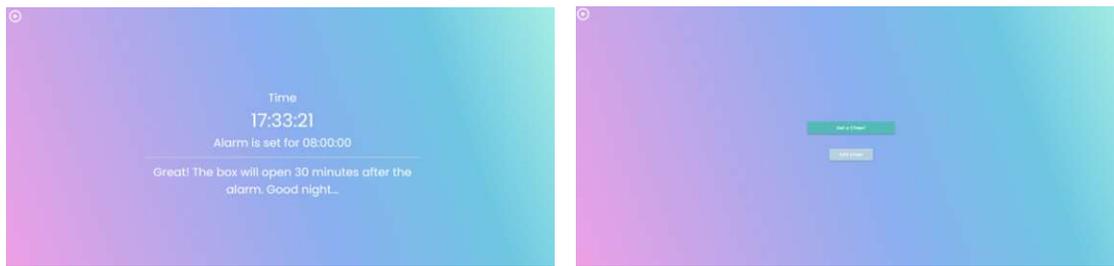


(a) Set a timer to lock your device for a customizable duration, determined by your preferences (b) Screen displayed after setting a custom lock duration and activating the device lock feature.

Figure 6.2: Lock Feature

6.2b. During the locking period, users were encouraged to focus on other tasks or activities while their phones remained physically inaccessible.

- **Gentle Wake:** With this feature, before going to bed, users can secure their devices in the aforementioned designated locker area and set the alarm for the next day. Users can replace the loud alarm ringtone on their smartphones with more soothing sounds for a gentler wake-up experience. During the first 30 minutes of the day, users' access to their digital devices is restricted, as shown in Figure 6.3a. Upon waking, the device remains locked for the first 30 minutes, allowing users to start their day without the distractions of social networking and online activities. The box also includes charging ports inside, allowing users to recharge their device batteries overnight.
- **Meditation:** This feature is designed to improve users' well-being and help them live a more positive life. Instead of starting the day with social media and being overwhelmed with irrelevant information that distracts their thoughts, the guided meditation feature directs the user's focus to internal sensations and emotions.
- **Therapy:** In certain situations, it is essential to seek the advice of a specialist. MBox facilitates referrals to nearby mental health professionals, providing relevant office information, contact details, and other essential information to help users connect with the right professional.
- **Cheer List:** MBox provides a positive reminder list to help users overcome stress, and low moments throughout the day. Users can personalize the list with things they love, quotes, poems, calming activities, and positive aspects of their lives. During the day, Mbox suggests items from the list to improve their mood, as shown in the figure 6.3b.
- **Water Intake:** While many people may not need a hydration reminder, some may benefit from it. The water intake reminder helps users stay hydrated by prompting them to keep track of their consumption.



(a) Gentle Wake Lock for 30-minute device restricted mornings

(b) User can click 'Get Cheer' for personalized uplifting messages

Figure 6.3: Features Promoting Positive Mood

- **Events:** We have integrated links to free events and group activities in our city, displaying relevant details such as event time and location. The user has the flexibility to filter the list and select an event that matches their current mood and preferences. Dining out, exploring new places, playing sports, reading, or dancing can all provide entertainment and help users relax.
- **Activity Tracker:** To make exercise engaging and fun for the user, Mbox introduces exercise challenges. The user can participate by tracking steps or performing other sports activities, which are then converted into step equivalents.

## Hardware

The central control hub was a Windows tablet with an intuitive touchscreen interface. The ESP32 microcontroller acted as a bridge between the application and the physical components, facilitating communication and controlling the solenoid lock. Python was used for the ESP32's web server functionality because of its simplicity and network communication capabilities. The solenoid lock, controlled by the ESP32 via a relay, provided precise access control to the shelves. All components were powered by a dedicated 12V power supply connected to a standard 220V power source. The hardware was housed in a custom laser-cut wooden case, which provided protection and enhanced the aesthetics of the prototype, as shown in Figure 6.1a.

## Software

A JavaScript library served as the underlying technology for building MBox's user interface. Its component-based architecture and declarative nature simplified the creation of reusable UI components and ensured efficient updates and rendering optimizations. Google Firestore, a NoSQL cloud-based database, was selected for efficient data storage and management. To host and deploy the Digital Detox companion, we relied on Netlify, a cloud platform designed for web application deployment. Features such as continuous deployment, scalability, and content delivery network (CDN) contributed to optimal performance and provided a reliable and efficient hosting environment.

### 6.3 Mixed Method User Study

We employed daily diaries as a means of collecting subjective information about participants' interactions and experiences with the MBox on a daily basis. These diaries served as reflective tools that allowed participants to document their thoughts, feelings, and behaviors related to technology use and engagement. The diaries consisted of a series of questions that participants answered for each day of the test period. In addition, interviews were conducted at the end of the seven-day testing period to obtain in-depth qualitative feedback.

#### 6.3.1 Participants and Procedure

The study comprised 7 participants (3 female, 4 male) with an age range of 22 to 29 years ( $M = 23.25$ ). Recruitment was conducted through word of mouth and online forums related to our university courses. Participants were shortlisted for the study through an initial survey that collected demographic information, current device usage time per day, and their feelings related to usage and motivation to reduce device usage. Participants who reported spending more than the average amount of time on their devices and who expressed motivation to reduce screen time were selected for the study. Informed consent was obtained from all participants prior to the start of the user study to ensure their voluntary participation. A brief tutorial was provided at the beginning to familiarize participants with MBox and how to use it. They were then instructed to take the prototype home and use it for 7 days to explore and cultivate a healthier relationship with technology. To supplement the data collection, participants were also provided with a printed diary to be completed daily to record their experiences and interactions with the MBox. After the 7-day period, participants returned to the lab and returned the MBox along with the completed diary. They participated in semi-structured interviews to reflect on their experiences with the prototype. The interviews covered aspects such as length of use, preferences, and challenges encountered. Each interview lasted about 25-30 minutes.

#### 6.3.2 Measurements

Quantitatively, we recorded participants' screen time and lock time. To ensure accuracy and to evaluate the final results, we compared screen times at the time of hardware pickup and upon return. Initial screen times were documented on participant consent forms during hardware pickup, and updated times were recorded during subsequent exit interviews. The study used a mixed-methods approach, with data collection topics including (1) overall feelings about using the technology, (2) accomplishments with the box, (3) most useful features and why, (4) changes in usage patterns, and (5) improvements and future directions. The thematic analysis was conducted by a core team of three researchers, one female and two males, all experienced in human-computer interaction (HCI) research. To facilitate the analysis process, an online whiteboard tool, Miro, was used for collaborative discussion and data categorization. The interviews were audio

recorded. The interviews were analyzed using the qualitative content analysis method by three researchers [May00]. The analysis of interview data in this study followed a structured process of transcription, coding, category creation, and theme development. The data categorization of each interview underwent a second review by at least one researcher to determine the final categorization.

## 6.4 Results

Statistical comparisons were performed using IBM SPSS Version 27.

### 6.4.1 Quantitative

Participants used the lock feature for extended periods of time, suggesting that MBox encouraged intentional screen time reduction. The average device lock time ranged from 36 minutes to 216 minutes, with a mean of 123.29 minutes and a standard deviation of 73.072 minutes. The distribution of average unplugged time showed negative skewness, indicating that the data were skewed toward longer unplugged times. Participants used the mindfulness aspect. The average meditation time reported by participants ranged from 0 minutes to 10 minutes, with a mean of 6.00 minutes and a standard deviation of 3.697 minutes. The kurtosis value suggested a slightly negatively skewed distribution, indicating that the data were slightly skewed toward shorter meditation durations. We used the Wilcoxon signed-rank test to compare the means of average screen time before and after the study. The Wilcoxon signed-rank test statistic with a corresponding p-value of 0.016 indicates a statistically significant difference between the means, with an effect size of -2.410. The results indicate a significant reduction in screen time during the 7-day intervention period, suggesting the effectiveness of the opt-out strategy. Intentional use of the lock feature during focused activities such as studying, cooking, socializing, or engaging in other tasks promoted mindful device use behaviors.

### 6.4.2 Qualitative

For the qualitative data that was collected through the daily diary and the interviews, we endeavored to make sense of all the notes, observations, and discoveries that we had recorded by using themes to categorize the data and build the following through-lines:

**The Lock Feature helps avoid distractions:** Based on the feedback from users, the Lock feature of the prototype appears to have both positive and negative aspects. Users found it easy to use and helpful in avoiding distractions, which suggests that it is an effective way to limit digital device usage. One participant said *“I really liked the Lock feature. It helped me stay focused and avoid distractions while I was trying to get work done”*. Locking one’s devices required planning ahead and adjusting to a new routine. Some users found the Lock feature inconvenient and challenging. Another participant reported *“I found it difficult to resist the temptation to check my phone, even when it*

*was locked away.*“ Another said *“It helped me focus on the present moment but I did find it challenging to completely detach from my phone for longer periods of time, so I had to adjust the lock duration accordingly.”*

**Impact of the Lock Feature:** Some users did not see a significant impact on their productivity, while others found it helpful in getting work done. This could be due to individual differences in work style and the types of tasks being performed. It may be worth exploring further how the Lock feature can be optimized for different types of users and tasks. Some users reported moments when they really needed to access their device but were prevented from doing so, which suggests that the feature may not be suitable for all users or situations. Our participant said *“The lock feature was a bit challenging for me because I have a busy schedule and need to be able to access my phone for work purposes. However, I did appreciate the concept behind it and found that using it during my free time was helpful in reducing my overall phone usage.”* Another reported *“There were moments when I really needed to access my phone, but the lock prevented me from doing so.”*

**Improved focus in the morning:** The Gentle Wake feature of the prototype suggests improved focus in the morning, and increased consistency in their routines. Additionally, users found that the feature helped them avoid phone distractions and reduced stress in the morning. One participant said *“The Gentle Wake feature was a great addition to my morning routine. I loved being able to focus on my healthy habits without being distracted by my phone.”* However, some users found the waiting time frustrating and the new routine challenging, as a participant said *“I found it challenging to wait for 30 minutes before accessing my phone, especially when I had to check my emails or messages urgently.”* Additionally, some users reported mixed feelings about the feature, highlighting the need to consider individual differences in preferences and routines. One participant reported *“I found it challenging to adjust to the new routine and sometimes forgot to unlock my phone for a longer period of time.”*

**Dual Nature of Meditation:** The feedback from users regarding the Meditation feature suggests that it has both positive and negative aspects. One participant said *“The guided meditation session was easy to follow and allowed me to clear my mind and reduce stress.”* Additionally, some users reported that the feature gave their day a positive start and helped them establish a positive mindset. However, some users found the feature too soothing, repetitive, and with a monotone voice. One mentioned during the interview *“The voice of the guided meditations was sometimes too soothing and put me to sleep.”* Another one said *“I found the voice guiding the meditation to be too robotic and not soothing enough.”* The lack of notifications was also reported as a potential area for improvement, as it could help users stay on track with their meditation goals.

**Cheer List Delight and Reservations:** For the Cheer List feature, users said that it is simple and fun to create their own lists. *“It was fun to create my own list of things that*

*make me happy and then see them randomly pop up when I needed a little pick-me-up. One challenge was trying to come up with enough cheers to make the list interesting, but overall I found it to be a great tool for boosting my mood.*“ However, there were some mixed reviews, like *“ The Cheer List feature was a bit too cheesy for me. I didn’t really like the idea of having to write down things that make me happy and then rely on a computer to suggest them to me. I would have preferred a more personalized approach, but I can see how it might be useful for some people.*“ Nonetheless, most users reported that they loved the feature and found it to be a nice surprise when they selected a random happy cheer.

**Reported Changes in Usage Patterns:** With screen time going down, participants had more time for activities such as reading and spending time with family. Users reported better decision-making skills, locking their phones for longer time stretches, and experiencing more focus. The Gentle Wake feature had a huge impact on their morning routines, resulting in them being less dependent on the phone and more aware of their habits. One participant said *“ I became more mindful of when and why I was using my phone, which helped me make better decisions about how much time I spent on it.”*. Another one reported *“I definitely saw a change in my usage pattern during the last 7 days. Initially, I was using the Lock feature as a way to control my phone usage, but as I got used to it, I found myself becoming more aware of my habits and making conscious decisions to limit my phone time even when the Lock feature wasn’t on.”*

**Suggestions for Improvement:** Users provided suggestions for future implementations, including a feature that offers healthy meal suggestions based on dietary restrictions and preferences, providing recipes and grocery lists to make meal planning easier. Another suggestion was a feature that helps set and track personal goals such as reading more books, learning a new skill, or saving money. The participant said *“I would like to see a feature that helps users set and track goals for personal development. This could include things like reading more, learning a new skill, or volunteering.”* Additionally, a feature that recommends local outdoor activities based on a user’s interests and fitness level would encourage people to get out and be active. Users also suggested a feature that helps find and support local community events and initiatives, provides access to virtual fitness classes or workouts, and connects users with local support groups for various issues such as addiction recovery.

### 6.4.3 Design Recommendations

By implementing the following design recommendations, MBox can become more effective in helping users maintain a healthy balance between their digital and real-life experiences:

- Improve user experience by providing greater flexibility in setting time limits and incorporating customizable options.

- Include an emergency unlock feature to address user concerns about being completely locked out in urgent situations.
- Offer a variety of lock modes to accommodate different user preferences.
- Use gamification techniques to make setting time limits more engaging and encourage regular use of the feature.
- Provide visualizations or progress trackers to showcase user achievements and encourage adherence to digital detox goals.
- Allow users to create a personalized wake-up routine.
- Allow users to select their favorite voices or soundscapes for a more immersive meditation experience.
- Introduce interactive elements, such as user-generated content, to motivate users to unplug from their devices.
- Implement sentiment analysis to suggest encouraging messages based on the user's mood or emotions, adding a personalized touch.

### 6.5 Conclusion

Our research focused on strategies to address growing concerns about excessive screen time and mindless use of digital devices, while respecting user autonomy. To strike a balance, we developed the "Mindful Box," a tangible opt-out approach designed to mitigate problematic digital use while promoting healthier digital habits. The box was carefully crafted based on insights from primary interviews and brainstorming sessions. In addition to the lock feature, our prototype integrated other features such as gentle wake-up support, meditation support, a cheer list for motivation, and water reminders to provide a comprehensive solution. We evaluated the effectiveness of MBox in a one-week in-the-wild study with seven participants. Our analysis showed that MBox, particularly its lock feature, significantly reduced average screen time. Users praised its effectiveness in combating distractions and recognized its potential to limit the use of digital devices. Feedback on the gentle wake-up feature indicated improved morning focus, improved routine consistency, and increased productivity. Participants reported increased self-awareness of their usage patterns, leading to more mindful choices and a daily intention to detox from technology by using the box's locking feature. The physical opt-out strategy proved effective and beneficial for all participants. They physically engaged by setting the time, placing the device in the drawer, pushing it shut, and clicking the lock. Participants reported that this physical interaction marked a moment of focus and redirection of time and energy to other activities. The gentle wake and meditation feature provided a valuable opportunity for participants to unwind, relax, and enjoy a few extra moments of personal time, especially in the morning. In conclusion, our work contributes to the ongoing exploration of digital detoxification strategies. By

addressing the challenges of excessive screen time, MBox represents a promising solution for promoting healthier digital habits. The design recommendations derived from user feedback will inform future iterations of the prototype, improving its effectiveness and user experience.

One promising avenue for future research is to enhance the locking feature by offering a range of locking modes, such as selective app blocking or specific time frames, to give users greater control and flexibility over their digital use. In addition, conducting large-scale and longitudinal studies can shed light on the long-term effects of digital detox interventions on individuals' well-being and behavior. Furthermore, studying the impact of digital detox on different age groups and demographics can provide valuable insights for tailoring strategies to meet the unique needs and circumstances of different populations.



# Part IV

## Contributions



# Results and Discussion

The qualitative data collected in the user studies explained in previous chapters was imported into a Miro board. Using thematic analysis <sup>1</sup>, we organized, rearranged, and analyzed the data. The data includes notes, feedback from interviews or diary studies, and observations. We put each piece of information on a sticky note on the digital board and laid them out in a way that we could see all of them on the digital whiteboard to get a clear overview of everything. We began to identify patterns and connections between the notes, grouping similar notes together while keeping the three research questions in mind. Once I had grouped the notes, we labeled the groups and listed the key findings for each theme (refer to 7.1). This directly addressed the research question posed in the introduction. After grouping, iterations, and adjustments were made by reshuffling the data to fit a specific research question.

## 7.1 Findings on Autonomy, Competence, and Relatedness

We analyzed the data through the framework of self-determination theory, focusing on how the systems we designed addressed the psychological needs of autonomy, competence, and relatedness. This approach enabled us to identify design features that fulfilled these needs and evaluate their impact on the overall user experience. As demonstrated by allowing users to personalize settings gives them a sense of control, providing adaptive feedback during skill-building tasks helps users grow, and incorporating social features such as sharing progress with friends fosters a sense of connection and belonging. Below we answer the research question - **RQ1: How can digital companion systems be designed to enhance autonomy, competence, and relatedness in user interactions?**

<sup>1</sup><https://www.lyssna.com/blog/analyzing-and-synthesizing-ux-research/> – Accessed Dec 2024

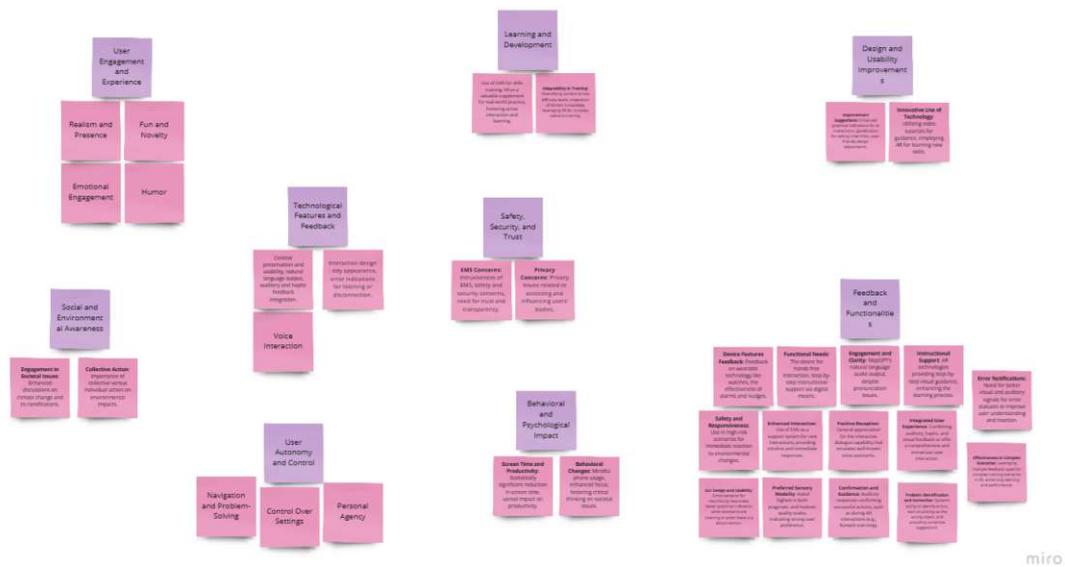


Figure 7.1: Snapshot of the Miro board illustrating the synthesis process, showcasing the organization and grouping of data during analysis.

### Reactive Systems

**Autonomy:** Participants appreciated the liberty to request assistance at their own discretion, which fostered a sense of autonomy. Avoiding any interruption to their natural workflow and enabling them to decide when to seek support autonomously avoids feelings of intrusion and empowers users to maintain control over their interactions. As shown by the Carbon Rebellion companion, participants demonstrated autonomy as most independently navigated to solutions without external facilitation. As revealed by the GIS AI companion, participants requested a mute button for voice output. Participants wanted control, they wanted the ability to ask multiple questions or execute multiple commands. Companion systems capable of adapting their responses in a reactive mode based on user preferences, such as adjusting the level of detail or feedback modalities, enhance the overall user experience. User convenience was enhanced by offering flexible time limit settings, customizable options, and a variety of blocking modes to suit different preferences, such as selective blocking for specific time periods, provided by the Mbox companion.

**Competence:** When the companion provided feedback directly related to the user’s current context and activity, participants felt the system understood their actions and helped them improve at the task at hand, whether that was reducing smartphone use or learning a new skill. When the user made an error, the companion offered suggestions to improve or correct it, helping to reinforce learning without causing overwhelm. When reactive companions provided step-by-step assistance in a structured

manner, participants felt supported in gradually building skills at their own pace. During the 7-day intervention phase, the Mbox companion demonstrated its effectiveness through a significant reduction in screentime, highlighting the success of the self-opt-out strategy. Participants intentionally used the locking feature during focused activities such as studying, cooking, social events, or other tasks, fostering more mindful behavior. To enhance user engagement, providing visualizations or progress trackers can help showcase achievements and support adherence to digital detoxing goals. As indicated by GIS AI companion, designing the GUI to maximize the map area and preserving context to enable seamless follow-up questions were identified as essential features to improve usability. As demonstrated by the Carbon Rebellion companion, delivering information in digestible, engaging chunks encouraged participants to think critically, understand the issues, and take meaningful action. These findings highlight the importance of designing companions that are contextual, supportive, and user-centered, empowering individuals to build skills and adopt mindful behaviors.

**Relatedness:** When the companion system provided supportive and empathetic responses, especially on sensitive topics, participants felt a sense of understanding and connection. As reflected in the Carbon Rebellion companion, which emphasized collective action over individual contributions, participants recognized the measurable global impact of small individual actions when adopted collectively by more people. When reactive companion systems adapted their communication style to align with the user's, participants experienced a stronger sense of connectedness. As illustrated by the Mbox companion, gamification techniques allowed participants to engage more with setting time limits and using the feature regularly. Participants felt motivated to disengage from their devices. Participants reported that sentiment analysis, which generated encouraging messages based on their emotions, provided a personalized touch that effectively supported their goals. GIS AI companions preserved conversational context by accessing past queries to maintain continuity, and their natural language audio output, along with interactive dialogue capabilities was well-received by users.

### Proactive Systems

**Autonomy:** Allowing users to customize the level of proactivity is crucial, as some may prefer frequent suggestions, while others may find them intrusive. As shown by the Skillab companion, participants indicated no loss of agency when using EMS. Participants reported retaining a sense of agency when using EMS. While the printable instructions allow for customization by skipping or combining steps, the Skillab session itself does not offer this flexibility. Some participants expressed a preference for having full control over the process. Suggestions or recommendations should be proactively offered while giving users the choice to accept or ignore them. As indicated by Professional Training in VR, learners could engage at their own pace with repetition, fostering greater self-assurance and reducing stress. Control emerged as a critical factor for the acceptance of the technology. Participants emphasized the importance of being in command, expressing discomfort with both the sensation and the perception of being controlled by the technology. For

digital detox applications, context plays a crucial role in maintaining user autonomy. Factors such as time of day or current activity can guide when to offer suggestions or intervene, ensuring that users remain in control of their experience.

**Competence:** Proactively identifying opportunities for learning or improvement allows the companion system to offer tips or resources in advance. As revealed by the Nudget companion, there was a significant decrease in app openings, with the median dropping from 8.8 to 5.2 times per day ( $Z = -2.023$ ,  $p = 0.043$ ). All three nudges helped participants reduce their news consumption, and participants reported becoming more aware of their daily app usage. They noted that the nudges made them conscious of their frequency and time spent on the app, enabling them to set their own time limits and feel in control of their usage. When patterns of behavior suggest a potential issue, the system can alert the user or propose alternative actions. As illustrated by the Watchful Detox companion, the sleep-tracking features were well received. Participants noted that this visibility enabled more informed decisions about smartphone interactions, fostering a mindful approach to app usage. By centralizing access to time and notifications, the watch decreased the temptation to explore other phone apps, lowering prolonged screen engagement. For apps with usage limits, there was a consistent reduction in usage across both passive and active weeks. Scaffolding techniques should be tailored to align with the user's current skill level to ensure effective support. Participants consistently cited better focus in VR environments due to the exclusion of external distractions. A strong sense of presence, closely aligning the virtual environment with reality, was identified as critical for user acceptance. While supervisory oversight remains essential, proficient users may require less assistance. Diversifying training content across difficulty levels and adapting it to different knowledge tiers is advisable, with expert collaboration crucial for content development. Despite EMS's potential to accelerate long and intensive learning processes, its application for learning guitar was met with reservations, indicating that its acceptance may vary based on task type and user expectations. As revealed by the Teleoperation companion, the use of EMS, combined with auditory and haptic feedback, reduced collision counts and shortened collision times. For Skillab, participants highlighted the significance of muscle actuation techniques for performing unfamiliar movements critical to the job. Some found EMS particularly helpful as a support system for entirely new interactions. Despite EMS's potential to accelerate learning processes, its application for learning guitar was met with reservations, indicating that its acceptance may vary based on task type and user expectations.

**Relatedness:** Companion promotes social engagement by suggesting connections with other users to encourage interaction and shared experiences. As demonstrated by the Nudget companion, participants reported reading the news most often when bored or during periods of free time with no planned activities. Many valued staying informed as a way to engage in meaningful conversations within their social circles, while some noted how specific news stories affected their overall well-being. The Interceptor feature, with its quotes, inspired some participants to connect with others, such as calling someone after

seeing a prompt. As shown by trainers using VR technology, realism, novelty, and fun were highlighted as key positives of VR training using companions, with trainees particularly emphasizing the fun aspect. For Skillab, participants described the companion as someone who "has your back," ensuring they were not left to complete tasks alone. Participants felt that the companion was available through many channels through the use of multi-model feedback, visual, audio, and tactile feedback.

### Takeaways in Context of the Companion Technology

In this dissertation, autonomy is reinterpreted beyond traditional notions of user choice or control to include contextual adaptation and self-imposed constraints. For example, Nudgit allows users to opt in to subtle, content-aware nudges while reading news, reinforcing autonomous decision-making without coercion. MapGPT supports autonomy by allowing users to interact naturally through speech, allowing users to direct their own exploration paths. With MapGPT Companion, simplifying complex GIS queries increased user confidence, however, some experienced users found the conversational interface too guided, demonstrating the need for skill support to adapt to user expertise levels. The Mbox Companion reflects a novel form of autonomy, where users voluntarily externalize control through a physical locking mechanism. This demonstrates that autonomy-supportive design can include tools that users intentionally use to restrict themselves, as long as the initiation and conditions remain user-driven. Autonomy is not a fixed state, but a negotiated interaction between user intent and system responsiveness, often modulated by the level of proactivity embedded in the system. While companion systems like Mbox allowed users to initiate technology lockouts themselves, some participants reported moments when their past choices (e.g., lockout duration) conflicted with their current needs, highlighting a tension between initial autonomy and ongoing flexibility. Competence is observed not simply as task completion, but as a felt sense of progress, confidence, and self-efficacy enabled by system feedback and design scaffolding. In the SkillLab Companion, AR overlays and EMS provide real-time, embodied feedback, making skill development tangible. Similarly, the VR Training Companion supports self-directed practice and progressive challenge exposure, enabling learners to build spatial memory and decision-making skills in safety-critical domains such as healthcare. Even with MapGPT companion, competence is fostered by reducing cognitive load, participants were able to query complex temporal-spatial data without requiring expert knowledge of map interfaces or query syntax. These companion artifacts demonstrate that competence can be fostered through the reduction of barriers, the provision of timely scaffolding, and the ability for users to experience tasks at their own pace. Relatedness, often underemphasized in technical systems, is reimaged to include both machine-mediated emotional resonance and social accountability through design. The Watchful Detox Companion, for example, encourages reflective engagement with digital habits and introduces gentle reminders tied to self-set intentions, cultivating a sense of being supported by the system in a non-intrusive way. In addition, its wearable nature invites subtle social presence. The Carbon Rebellion companion goes even further, using interactive narrative, humor, and emotional design to position the user within a broader collective movement. By simulating

the personal and systemic consequences of environmental decisions, it creates a sense of belonging to a cause, expanding SDT's notion of relatedness from interpersonal connection to values-based alignment.

Using novel interaction modalities such as EMS and immersive AR/VR environments, our work explores the tensions between autonomy and system-driven intervention. The SkillLab and Watchful Detox companion systems demonstrate that 1) Autonomy can be maintained even in physically directive environments if users retain control over entry/exit and pacing. 2) Interventions must be designed to support rather than override user intentions, even subtle nudges must be interpretable and reversible. The Teleoperation Companion extends this discussion by addressing the shared control of tasks between humans and machines in remote collaboration settings. By facilitating cooperative action rather than rigid handoffs, the Teleoperation Companion exemplifies how autonomy can be supported in dynamic, interdependent systems. We also emphasize emotionally aware systems, like humor in Carbon Rebellion played a significant role in relational bonding and psychological resonance suggesting the importance of affective modulation in facilitating relatedness, an area not deeply explored in classical SDT. It promoted value-based alignment, but some users reported emotional disengagement when the narrative felt too abstract or "preachy". This suggests that relational resonance requires careful emotional calibration. It is proposed that affective scaffolding-humor, encouragement, validation can substitute for or complement human relationships in certain contexts.

### 7.2 Defining Characteristics of Companion Technologies

We began by categorizing user feedback into recurring themes, reflecting what fostered the perception of companionship in technology. We focused on user-reported experiences (case-specific insights) and selected quotes that reflected on companionship experiences with the prototype, such as a participant describing the Watchful Detox Companion's nudging feature as *"effective in breaking bad habits"*, or another praising the Skillab Companion for *"preventing mistakes and making learning by doing more rewarding."* Similarly, the Carbon Rebellion Companion's humor element was highlighted by participants for *"making the content relatable and engaging despite its serious subject matter."* In accordance with our analysis, which addresses RQ2, the perception of a technology or an artifact as a "companion" is characterized by the following features:

**Always On, Always Available When Needed:** A consistent and always-available presence is one of the defining characteristics of companion technologies. These systems are accessible and ready to assist users whenever needed, creating a sense of security and reliability. Both proactive and reactive companions were appreciated by users for their immediate availability. For example, in the Watchful Detox companion, where participants wore the watch, one participant reported [ ... ] *Maybe just like being shown how much you use your phone on a daily basis, which the watch facilitates - you're consciously thinking about it.*

**Consistency in Task Assistance:** Artifacts that are reliable are perceived as dependable companions. For instance, in the obstacle avoidance study, users appreciated the teleoperation companion, which employs EMS for haptic feedback to prevent collisions. It not only reduced collisions but also shortened their collision duration. One participant reported *“But if it tells you OK, you have to do something, then you are more efficient with separating the tasks.”*

**Providing Support Without Overstepping:** Providing appropriate levels of assistance without overstepping is key to the artifact being liked as a buddy/companion. The Nudgit companion, for example, offered a content filtering option that allowed users to customize what they wanted to see and the companion to not overstep and automatically decide what the user should not see, which worked well for the user. One participant reported *“I realized that hiding news from Ukraine and Russia doesn’t affect my life badly. Before that, it was influenced by negativity and bad vibes.”*

**Understanding and Responding to User Context:** Context-aware functionality is crucial for a companion system to behave intuitively and provide relevant, timely support, which in turn leads to the perception of a companion that understands everything the user is doing and responds appropriately. The Skillab Companion, for example, gave users the impression of being supported and understood, preventing mistakes, and fostering confidence during task completion. One participant remarked: *“It prevents doing some mistakes and also you have this Learning by Doing and getting rewards feeling.”*

**Attentive Multi-modal Support:** A system that responds promptly and appropriately to user actions using multiple modalities gives the impression of attentiveness and understanding, fostering a sense of collaboration and support. This sense of collaboration is described by a participant as ‘the system having their back’, when interacting with Skillab companion. The Skillab Companion’s step-by-step guidance and interactive features, like Vumark scanning, were described as engaging and game-like, enhancing the overall experience for participants. For Skillab companion, one participant said *“It was more like playing games than actually doing work.”*

**Sense of Shared Purpose:** Artifacts that guide users toward achieving personal goals foster a sense of shared purpose. This also gives users the perception that the system is on their side, working collaboratively as part of their team. The Watchful Detox Companion, for instance, encouraged users to improve their habits by leveraging features like heart rate monitoring and sleep tracking. One participant described it as *“having a goal to live up to.”*

**Fulfilling Roles Beyond Utility:** To be seen as more than a tool, a companion must assume roles like teacher, mentor, or caregiver. For example, the Nudgit companion concealed negative content, fostering well-being, while the Watchful Detox Companion assisted users in monitoring screen time, showcasing the breadth of roles companions can fulfill. For the Medical Trolley training companion, for example, the participants

indicated that they perceived the companion to be akin to a virtual mentor. A participant said *"The repetition makes it totally memorable. It's really not the real world, but very close. You are not afraid of making mistakes, trying things out, and training."*

**Supporting User Well-Being Through Interaction:** Artifacts that address social and emotional needs enhance the well-being of the user and have been reported to be 'companions that look after the user'. Apart from the lock Feature helps avoid distractions using the Mbox Companion, suggestions from participants included features for meal planning, goal setting, and personal development tracking, showing how interaction supports balance and emotional connection. One participant said *"The guided meditation session was easy to follow and allowed me to clear my mind and reduce stress."*

**Fostering Relatedness Through Interaction:** Artifacts that create engaging connections become valuable resources for users. For instance, the Carbon Rebellion narrative emphasized collective action, resonating with users who valued the broader impact of their decisions. A participant highlighted, *"Even if the system is much bigger than you, it still matters what you do because if everyone does it, it has an impact. Both sides [of climate change] are shown [in the narrative], not just one side or the other."*

**Meaningful Exchange:** Collaborative task completion and meaningful exchanges foster partnership, which leads to the perception of having a companion. For example, professional training in VR connected theoretical and practical knowledge, helping users gain confidence in real-world scenarios. For example, when it came to the usability of MapGpt Companion, our participants reported that it was helpful, but beyond just being helpful and getting the job done, they also appreciated the human-like voice-based interaction. One participant said *'cool application! works actually really well,'* another even went so far as to say *'natural voice is better than Google Translate'*.

**Sense of Humor:** Humor can be an effective tool for engagement. in the case of the Twist, with the Carbon Rebellion, all participants exhibited a uniform response in the form of either a muted chuckle or a smile. This demonstrates that humor plays a role in engaging and amusing people. Addressing that, one participant said that *"even if everyone in continent became green fanatics, as long as the politicians don't change, nothing big is going to happen"*.

**Support for Personal Reflection:** Artifacts that encouraged and facilitated reflection, whether on a topic such as climate change or on their own smartphone use, were seen as helpful. For example, for Watchful detox companion, one participant reported *And what was more a statistic that made me see how many times I used to unlock my phone, which I didn't expect at all. It was like 100 times or more. And that's a problem at least in my eyes. And yeah, I think the app does a good job of displaying all the statistics really well.*

## 7.3 Guidelines Summnerized

The guidelines were derived from a meta-analysis of the synthesized data collected through empirical research on both proactive and reactive systems. The guidelines were formatted in line with best practices in usability and interaction design, ensuring clarity, actionability, and user-centered principles. These guidelines are important for researchers, user experience (UX) designers, behavioral psychologists, educational and training professionals, and software developers and engineers. Researchers and academics can use these findings to explore user interaction patterns, psychological needs, and the effectiveness of companion systems. User experience designers can and should apply these insights to craft user-centered designs that enhance users' autonomy, competence, and relatedness. Behavioral psychologists will find these results valuable for understanding how companion systems influence emotional responses and promote well-being, as well as for integrating psychological principles into system design. Educational and training professionals can use these companion systems to develop skills, encourage self-directed learning, and boost user motivation in educational settings. Software developers and engineers can use these insights to create and implement technical features that align with the identified design principles, such as adaptive responses, multi-modal feedback, and customization options, ensuring that companion technologies are both effective and engaging. We address RQ3, **“Which guidelines can be derived for the design and development of companion technologies to ensure alignment with user psychological needs?”**, by formulating the following guidelines:

**User Autonomy and Control:** These guidelines focus on empowering users to make decisions and maintain control over the interaction.

- Ensure users have clear control over all operations while interacting with the companion, including the ability to seamlessly start, stop, and modify functions.
- The companion should assist the user in making decisions by providing cognitive support such as memory aids, task organization tools, and reminders, and not make a decision on behalf of the user.

**Personalization and Adaptability:** These guidelines emphasize aligning the system's behavior with individual user needs, preferences, and capabilities.

- Align the companion's functionality with the user's routines and timeframes to suit their schedules and preferences.
- Assess users' competence levels and provide tailored assistance or challenges that match their abilities.
- Ensure the companion system's presence feels unobtrusive, whether as wearable tech, mobile apps, or voice-activated systems, prioritizing user comfort.

**Collaborative and Relational Design:** These guidelines aim to create a sense of partnership and connection between the user and the system.

- Design the companion system to act as a facilitative assistant rather than an authoritative figure.
- Foster a sense of shared goals, positioning the companion as a collaborator helping users improve and succeed.
- The companion must respond appropriately to user emotions to enhance the sense of connection and relatability with the system.
- The companion should foster peer-to-peer interaction and incorporate opportunities for users to connect with others who share similar interests or objectives.

**Cognitive and Emotional Support:** These guidelines highlight the importance of reducing cognitive load and supporting users emotionally and mentally.

- The companion should reveal information progressively to reduce cognitive load and help users manage complex tasks more effectively.
- The companion should provide immediate, contextually relevant feedback to demonstrate attentiveness to user actions.
- The companion should encourage positive behaviors, such as active living, healthy habits, and mindfulness, through thoughtfully designed interactions and reinforcement techniques.

### 7.4 Discussion

The Bhagavad Gita is an example of how companionship transcends mere functionality and embodies principles of trust, guidance, and mutual support. Krishna's role as Arjuna's charioteer not only provided strategic and spiritual guidance but also exemplified a form of companionship rooted in empowering individuals while respecting their autonomy and emotional state. This perspective is consistent with contemporary theories in HCI that advocate designing technologies that address not only functional needs, but also psychological and emotional dimensions [DR08, HDG10]. Previous research has highlighted the gap in developing technologies that address psychological needs, often focusing solely on functionality [HDG10]. Our work showcases that companion technologies that prioritize psychological needs drive deeper engagement and satisfaction. Proactive companions, such as the VR Training System and the SkillLab AR companion, effectively increase competency by enabling skill acquisition in safe, immersive environments. These findings are consistent with previous work showing VR and AR's value for structured learning [GGBZ21, TPB<sup>+</sup>17]. In addition, the integration of collaborative

features in these systems supported relatedness, echoing Laschke et al.'s (2020) [LBNH20] emphasis on designing for teamwork and professional satisfaction. Reactive systems, such as the Mbox, fostered autonomy by allowing users to define their engagement parameters, supporting findings from previous studies [BZSP19]. However, while reactive systems excelled at providing user control, their potential to foster competence and connectedness was more limited compared to proactive counterparts. Proactive and reactive companions each offer distinct strengths and challenges. Proactive systems have been shown to excel in anticipating user needs and providing timely assistance. For example, the MapGPT companion preemptively offered suggestions tailored to user queries, reducing cognitive load, thereby aligning with the findings of prior research conducted by Garcia et al. (2020) [GDSM20]. However, overly proactive systems can seem too much like they're controlling users [YSSMM12]. Reactive companions, on the other hand, prioritize user control and customization. The Mbox exemplified this by enabling users to define their own locking and usage parameters, fostering a sense of autonomy. However, its reactive nature limited its ability to dynamically adapt to evolving user needs, which could constrain its overall effectiveness. When comparing the two approaches, the integration of both proactive and reactive elements appears most effective. This pattern is consistent with findings in psychological needs research, in particular the distinction between externally imposed structure and internally chosen constraints [RD00, SEKK01]. Systems like the Mbox provide users with a sense of willful control through the intentional setting of constraints, which is consistent with SDT's nuanced view of autonomy, not as absolute freedom, but as self-supported action. This echoes the idea put forward by Hassenzahl [HDG10] that good design should facilitate the user's experience by supporting meaningful, self-congruent goals.

Also, the interaction modalities of companion systems have a significant impact on the user experience. Previous research emphasized the importance of multi-modal input and output [EEV<sup>+</sup>12]. Our case studies reinforced this, showing that systems that incorporate multiple modalities, such as visual, auditory, and haptic feedback, are more engaging and effective. For example, the VR training companion used immersive visual and interactive elements to improve spatial orientation and procedural skills, building on the findings of Schrom-Feiertag et al. (2017) [SFSS17]. Similarly, the SkillLab AR Companion's use of EMS for haptic feedback provided a novel modality that addressed the limitations of tactile experiences identified by Makransky et al. (2019) [MBGM19]. However, the integration of EMS also highlighted potential trade-offs with user autonomy that will need to be carefully considered in future designs. This tension has been similarly noted in previous literature on adaptive assistive systems, particularly in the context of physical interfaces where system initiative can compromise perceived user control [PK12]. In the case of the Teleoperation Companion, we found that shared control models, where the system gently physically nudges the users, and the users could fluidly negotiate agency with the system, helped maintain perceived autonomy while still providing guidance. This is consistent with findings from Petrick and Foster's bartender robot studies [PF13], where multimodal interactions improved perceived cooperativeness and usability.

The tactile interface of the Mbox and the natural language processing capabilities of the MapGPT companion demonstrated the value of context-sensitive interactions. However, challenges in real-world scenarios, such as environmental noise affecting voice commands, highlighted the need for robust context awareness. These findings align with prior research [SGM07] on the complexities of multi-modal fusion. This research highlights the dual challenge of addressing the pragmatic and experiential dimensions of technology companionship. While pragmatic aspects focus on the efficiency and functionality of systems, experiential dimensions aim to cultivate deeper emotional and relational connections. Integrating these dimensions requires careful balance, as overly functional systems risk being perceived as impersonal, while overly relational systems may fail to deliver the expected benefits. This balance is reflected in the psychological design strategies discussed by Laschke et al. (2020) [LBNH20] and Burmester et al. (2019) [BZSP19], both of which argue for designing for meaningful experiences that enhance well-being while not overwhelming users with unnecessary complexity or impact. Watchful Detox used wearable feedback to increase awareness without overwhelming the user, reflecting SDT principles of autonomy-supportive scaffolding [DR13]. In our studies, we also observed that need satisfaction is not static. It is dynamic, contextual, and shaped by modality, task, and timing. For example, MapGPT initially supported competence by simplifying search complexity, but some advanced users felt constrained by its oversimplification-highlighting a need for adaptive complexity, as suggested by Peters et al. (2014) [PHWH14]. Overall, this dissertation offers a companion technology specific perspective on SDT. Across the companion artifacts, these psychological needs were supported in different ways depending on the role, modality, and level of proactivity of the companion. This work contributes to a more nuanced understanding of how companion technologies can be designed to respond to users' changing needs and contexts, complementing existing SDT-informed approaches in HCI.

# Conclusion

The dissertation explores how SDT can inform the design and development of companion technologies. By addressing the psychological needs of autonomy, competence, and relatedness, it aims to enhance user interactions and foster meaningful engagement. The research investigates three primary questions: how digital companion systems can be designed to support autonomy, foster competence, and promote relatedness in user interactions; what the defining characteristics are that enable individuals to perceive technology as a "companion"; and what guidelines can be derived for designing technologies that align with user psychological needs. To answer these questions, the dissertation employs a mixed-methods approach, integrating qualitative and quantitative methods. All case studies are presented, examining proactive and reactive companions in different contexts. The systems utilize diverse interaction modalities, such as haptic, visual, and auditory feedback, to address user needs effectively. The presented case studies illustrate how carefully designed technologies can transcend mere functionality, fostering engaging and supportive experiences that serve as companions to the user.

Proactive companions anticipate user needs and act autonomously. These companion systems were shown to: a) enhance autonomy by offering flexible options for users to interact at their own pace; b) build competence by providing structured, repeatable training sessions that help users master tasks; c) foster relatedness by integrating collaborative features that encourage them to get in touch with their peers and offer feedback that feels empathetic and supportive. For instance, the VR training system enabled participants to practice high-risk tasks in a safe environment, such as medical procedures and electrical work, which helped reduce anxiety while increasing confidence and skill proficiency. Reactive companions respond to user-initiated actions, tailoring their behavior to specific inputs. Key findings highlight that: a) autonomy is supported by allowing users to control reactive systems, such as enabling or disabling features when needed; b) competence is reinforced through context-sensitive feedback that helps users improve their performance over time; c) relatedness is fostered by providing empathetic

responses and personalization, making users feel understood and valued. Additionally, it demonstrated the potential impact of collective action and encouraged participation in a community-driven initiative. These reactive systems addressed practical challenges, such as reducing screen time, and improving task focus, demonstrating their alignment with SDT principles.

The dissertation offers practical guidelines for the design of companion technologies. These guidelines emphasize enabling users to maintain autonomy by providing clear controls for starting, stopping, and modifying system functions; supporting competence through tailored feedback, progressive learning techniques, and scaffolding to match skill levels; fostering relatedness by designing systems that are empathetic, socially aware, and capable of encouraging meaningful connections; balancing proactive and reactive behaviors to ensure systems are neither intrusive nor overly passive; and ensuring the systems are unobtrusive, intuitive, and adaptable to individual user needs and preferences. These guidelines are actionable and provide a strong foundation for developing technologies that engage users while promoting intrinsic motivation and well-being.

**Future Work:** The findings of this dissertation provide a foundation for further investigation in several areas. First, it is imperative to conduct long-term studies to examine the evolution of user relationships with these companion technologies over time. A deeper understanding of the lifecycle of these relationships, including potential shifts in user trust, reliance, and expectations, will provide insights into how to sustain user engagement. Secondly, the application of companion technologies in domains such as personalized healthcare, remote work collaboration, and creative industries may yield novel use cases. For example, healthcare companions could assist in managing chronic conditions by offering tailored guidance, while creative industry companions could support artistic workflows by providing real-time feedback and inspiration. Another crucial area for future research is the integration of AI capabilities, such as real-time emotion recognition and natural language processing, with the objective of enhancing personalization and responsiveness. However, as companion systems become increasingly autonomous, it is imperative that ethical considerations around data privacy, user agency, and transparency be addressed with the utmost rigor. It is of the utmost importance that companions are designed in a manner that respects user boundaries and provides clear explanations of their behaviors. It is imperative that companion technologies be inclusive and adaptable to disparate cultural contexts, thereby ensuring that they meet the psychological needs of users across the globe. Finally, future research could investigate the development of hybrid systems that integrate proactive and reactive elements in a dynamic manner, adapting their behavior based on user preferences and situational demands. Such hybrid assistants have the potential to transform interaction design by creating systems that truly embody a collaborative and supportive approach, dynamically adjusting their level of initiative to provide timely assistance when needed while maintaining user control based on contextual signals such as task complexity, user state, or preference history. For example, a system could remain in a reactive state during routine interactions, but switch to a proactive mode when a user shows signs of stress, inattention, or hesitation,

---

similar to the adaptive strategies seen in assistive robotics or intelligent tutoring systems. This adaptability would allow systems to calibrate their presence in a way that feels both supportive and unobtrusive. Future research could explore how users perceive this flexibility, how transitions between modes affect trust and usability, and how such systems perform in domains where task demands fluctuate, such as creative workflows, or assistive healthcare.



# List of Figures

1.1	Case studies domains linked to the SDT aspects. . . . .	8
1.2	Overview of prototypes developed for this dissertation. . . . .	10
1.3	This chart illustrates the flow of chapters and their contributions to the research questions. . . . .	13
3.1	Hallway, the starting point of the scenario (left), and the living room of the virtual flat (right). . . . .	33
3.2	Voltage tester, test lamp and two locks (left), and the fuse box in the hallway (right). . . . .	34
3.3	The view of the user when starting the scenario (left), user’s view of the hallway with pointing teleport (middle), and a room to be marked as visited (right). . . . .	37
3.4	The path leading to the first room (016) in the VR (left) and the real hallway (right). . . . .	37
3.5	The real medical trolley (left), the virtual trolley and the whole setup with buttons (middle), and a detailed picture of the top of the trolley (right). . . . .	40
3.6	Participant training in VR (left), participant’s view of the trolley (middle), the buttons next to the trolley (right). . . . .	41
3.7	Instructions board with step-wise descriptions. Example: “Place the 1. laminate tile (with the marker in the left corner) parallel to the wall with approx. 1cm space between the wall and tile. If finished, take the 2. laminate tile and scan it.” . . . . .	53
3.8	Participant receiving EMS assistance in the last tutorial stage. . . . .	56
3.9	User Study Setup. . . . .	57
3.10	Sample craftwork from the study participants. . . . .	58
3.11	Comparison of the overall task performance for Skillab and the Paper instructions. . . . .	60
3.12	Views of the two subtasks, right before and after scanning. . . . .	70
3.13	Plots of the means and 95% confidence intervals of the two UEQ-S scales and of the Task load - [b: Baseline, ab: Auditory, be: EMS, abe: Bi-modal auditory-haptic.] . . . . .	72
3.14	Images were used to give study participants an impression of the scenarios. . . . .	80
3.15	Affinity mapping of gathered interview statements - positive. . . . .	84
3.16	Affinity mapping of gathered interview statements - negative. . . . .	84

4.1	In 4.1a the home screen is shown with disabled nudges, whereas in 4.1b, the nudges are enabled, and the user is trying to bypass the <i>Opening-Counter</i> . 4.1c and 4.1d show the entry page of a news platform as soon as the user opens it with the difference that the <i>Content-Filter</i> is activated in 4.1d and hides the articles of 4.1c as they contained keywords about the Ukrainian war or the pandemic. In 4.1e the <i>Interceptor-View</i> intervenes in the user's reading flow and draws the user's attention to the reading time. . . . .	97
4.2	Watch face example and early sketches. . . . .	109
4.3	User interface of <i>Watchful</i> Application. . . . .	111
4.4	Color consistency per application across views and devices. . . . .	112
4.5	Health data visualizations for the last 24 hours. . . . .	113
4.6	Explanation of the available fields of the <i>Watchful</i> watch face that was supplied to the participants. . . . .	114
4.7	<i>Watchful's</i> watch application screens. . . . .	114
4.8	Data flow between all components. . . . .	115
4.9	Transforming descriptive event data to data points for easier analysis. . .	118
4.10	Analysis of weekly usage and changes for both overall and application-specific screen time. . . . .	119
5.1	General data architecture of MapGPT. . . . .	133
5.2	MapGPT software architecture]Software architecture of MapGPT and its GIS.	135
5.3	Zeitlinie GUI . . . . .	138
5.4	analysis [BBP22]. . . . .	142
5.5	On the left, the landing page of the narrative; on the right, the community impact background, with a highlighted user quote: " <i>If everyone works together, something can actually happen.</i> " . . . . .	151
5.6	Interactive Elements and Controls in the narrative. . . . .	156
5.7	Diagram illustrating the narrative within Carbon Rebellion. . . . .	157
5.8	Key moments from narrative's main scene to community effort and call to action. . . . .	158
5.9	Main scenes for the three eco-challenge quests. . . . .	159
5.10	<i>The Twist</i> in the narrative. . . . .	162
5.11	Examples of 2D assets created using AI tools. . . . .	164
5.12	Main Game and Zoom Out views. . . . .	164
6.1	Laser-cut wooden box containing a Windows tablet, microcontroller, and solenoid locks, with the tablet serving as the host for the prototype application.	179
6.2	Lock Feature . . . . .	180
6.3	Features Promoting Positive Mood . . . . .	181
7.1	Snapshot of the Miro board illustrating the synthesis process, showcasing the organization and grouping of data during analysis. . . . .	192

# List of Tables

1.1	Summerized Research Questions. . . . .	7
1.2	Summary of Empirical Contributions . . . . .	14
3.1	Benefits and Challenges of VR Training. . . . .	44
3.2	This table shows the different dimensions along which we categorized EMS-based systems. This list was elaborated by reviewing recent literature on the topic. . . . .	78
3.3	Utilized TAM dimensions with the respective number of questionnaire items and scale reliability (Cronbach's $\alpha$ ). . . . .	81
3.4	Medians and interquartile range (IQR) of the TAM dimensions in the investigated scenarios. . . . .	82
3.5	Summary of identified themes and they mentions across the four scenarios. . . . .	89
4.1	Study Phases Description. . . . .	116
5.1	Survey tasks. . . . .	140
5.2	Table displaying the GHGe values for the food eco-challenge quest. . . . .	160
5.3	Table displaying the GHGe values for the transportation eco-challenge quest. . . . .	161



# Bibliography

- [AA96] Richard H Audet and Gerald L Abegg. Geographic information systems: Implications for problem solving. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, 33(1):21–45, 1996.
- [AB20] Simon Amez and Stijn Baert. Smartphone use and academic performance: A literature review. *International Journal of Educational Research*, 103:101618, 2020.
- [ABLPS14] Jennifer H Allen, Fletcher Beaudoin, Elizabeth Lloyd-Pool, and Jacob Sherman. Pathways to sustainability careers: building capacity to solve complex problems. *Sustainability: The Journal of Record*, 7(1):47–53, 2014.
- [Abt70] Clark C. Abt. *Serious games*. Viking Press, New York, 1970.
- [AC21] Paul Adenot and Hongchan Choi. Web Audio API. W3C Recommendation, W3C, June 2021. <https://www.w3.org/TR/2021/REC-webaudio-20210617/> [Accessed: 10 March 2024].
- [ACB21] Anshika Arora, Pinaki Chakraborty, and MPS Bhatia. Intervention of wearables and smartphones in real time monitoring of sleep and behavioral health: an assessment using adaptive neuro-fuzzy technique. *Arabian Journal for Science and Engineering*, pages 1–26, 2021.
- [ACB22] Anshika Arora, Pinaki Chakraborty, and MPS Bhatia. Intelligent behavioral health analysis in youth using real-time smartphone and wearable data. In *Proceedings of International Conference on Communication and Computational Technologies: ICCCT 2022*, pages 653–666. Springer, 2022.
- [ACC<sup>+</sup>13] Juan C Augusto, Vic Callaghan, Diane Cook, Achilles Kameas, and Ichiro Satoh. Intelligent environments: a manifesto. *Human-centric Computing and Information Sciences*, 3:1–18, 2013.
- [ACK<sup>+</sup>15] George Adamides, Georgios Christou, Christos Katsanos, Michalis Xenos, and Thanasis Hadzilacos. Usability guidelines for the design of robot

- teleoperation: A taxonomy. *IEEE Transactions on Human-Machine Systems*, 45(2):256–262, April 2015.
- [ADK<sup>+</sup>18] Edmond Awad, Sohan Dsouza, Richard Kim, Jonathan Schulz, Joseph Henrich, Azim Shariff, Jean-François Bonnefon, and Iyad Rahwan. The moral machine experiment. *Nature*, 563(7729):59–64, 2018.
- [AG11] J Ignacio Aguaded-Gómez. Niños y adolescentes: nuevas generaciones interactivas= children and young people: the new interactive generations. *Niños y adolescentes: nuevas generaciones interactivas= Children and Young People: the New Interactive Generations*, pages 1–4, 2011.
- [AGMF13] Fraser Anderson, Tovi Grossman, Justin Matejka, and George Fitzmaurice. Youmove: enhancing movement training with an augmented reality mirror. In *Proceedings of the 26th annual ACM symposium on User interface software and technology*, pages 311–320, 2013.
- [AJL22] Mesut Akdere, Yeling Jiang, and Flavio Destri Lobo. Evaluation and assessment of virtual reality-based simulated training: exploring the human–technology frontier. *European Journal of Training and Development*, 46(5/6):434–449, 2022.
- [AM17] Mayank Aggarwal and Mani Madhukar. Ibm’s watson analytics for health care: A miracle made true. In *Cloud Computing Systems and Applications in Healthcare*, pages 117–134. IGI Global, 2017.
- [AO09] Lucy Avraamidou and Jonathan Osborne. The role of narrative in communicating science. *International Journal of Science Education*, 31(12):1683–1707, 2009.
- [ARARU<sup>+</sup>11] Sebastian Albrecht, Karinne Ramirez-Amaro, Federico Ruiz-Ugalde, David Weikersdorfer, Marion Leibold, Michael Ulbrich, and Michael Beetz. Imitating human reaching motions using physically inspired optimization principles. In *2011 11th IEEE-RAS International Conference on Humanoid Robots*, pages 602–607. IEEE, 2011.
- [AS12] Roberto Aparici and Marco Silva. Pedagogía de la interactividad= pedagogy of interactivity. *Pedagogía de la interactividad= Pedagogy of Interactivity*, pages 1–16, 2012.
- [ASVR07] Wokje Abrahamse, Linda Steg, Charles Vlek, and Talib Rothengatter. The effect of tailored information, goal setting, and tailored feedback on household energy use, energy-related behaviors, and behavioral antecedents. *Journal of environmental psychology*, 27(4):265–276, 2007.
- [AT08] Alison Hope Alkon and Michael Traugot. Place matters, but how? rural identity, environmental decision making, and the social construction of place. *City & Community*, 7(2):97–112, 2008.

- [AWF17] Christiane Attig, Daniel Wessel, and Thomas Franke. Assessing personality differences in human-technology interaction: an overview of key self-report scales to predict successful interaction. In *International Conference on Human-Computer Interaction*, pages 19–29. Springer, 2017.
- [Azu97] Ronald T Azuma. A survey of augmented reality. *Presence: teleoperators & virtual environments*, 6(4):355–385, 1997.
- [Bam13] Sebastian Bamberg. Changing environmentally harmful behaviors: A stage model of self-regulated behavioral change. *Journal of Environmental Psychology*, 34:151–159, 2013.
- [Bar15] Woodrow Barfield. *Fundamentals of wearable computers and augmented reality*. CRC press, 2015.
- [BB14] Knud Böhle and Kolja Bopp. What a vision: The artificial companion. a piece of vision assessment including an expert survey. *Science, Technology & Innovation Studies*, 10(1):155–186, 2014.
- [BBC06] BBC. BBC - Science & Nature - Climate Challenge game, 2006. publisher: British Broadcasting Corporation.
- [BBG<sup>+</sup>11] Susanne Biundo, Pascal Bercher, Thomas Geier, Felix Müller, and Bernd Schattenberg. Advanced user assistance based on ai planning. *Cognitive Systems Research*, 12(3-4):219–236, 2011.
- [BBP20] Ryan L Boyd, Kate G Blackburn, and James W Pennebaker. The narrative arc: Revealing core narrative structures through text analysis. *Science advances*, 6(32):eaba2196, 2020.
- [BBP22] Jonas Blattgerste, Jan Behrends, and Thies Pfeiffer. A web-based analysis toolkit for the system usability scale. In *Proceedings of the 15th International Conference on PErvasive Technologies Related to Assistive Environments*, pages 237–246, 2022.
- [BC94] G Burdea and P Coiffet. *Virtual reality technology*.–new york: John wiley&sons, 1994.
- [BC17] Fabio Buttussi and Luca Chittaro. Effects of different types of virtual reality display on presence and learning in a safety training scenario. *IEEE transactions on visualization and computer graphics*, 24(2):1063–1076, 2017.
- [BC19] Virginia Braun and Victoria Clarke. Reflecting on reflexive thematic analysis. *Qualitative research in sport, exercise and health*, 11(4):589–597, 2019.

- [BC21] Virginia Braun and Victoria Clarke. One size fits all? what counts as quality practice in (reflexive) thematic analysis? *Qualitative research in psychology*, 18(3):328–352, 2021.
- [BCDM<sup>+</sup>12] Luca Berardinelli, Dajana Cassioli, Antinisca Di Marco, Anna Esposito, Maria Teresa Riviello, and Catia Trubiani. Vision as a support to cognitive behavioural systems. In *Cognitive Behavioural Systems: COST 2102 International Training School, Dresden, Germany, February 21-26, 2011, Revised Selected Papers*, pages 131–143. Springer, 2012.
- [BCF12] Daniel Belanche, Luis V Casalo, and Carlos Flavián. Integrating trust and personal values into the technology acceptance model: The case of e-government services adoption. *Cuadernos de Economía y Dirección de la Empresa*, 15(4):192–204, 2012.
- [BCF16] Rajan Balakrishnan, Elanchezhian Chinnavan, and Tan Fei. An extensive usage of hand held devices will lead to musculoskeletal disorder of upper extremity among student in amu: A survey method. *Int J Phys Educ Sports Health*, 3(2):368–372, 2016.
- [BDMS<sup>+</sup>16] Ralf Barkemeyer, Suraje Dessai, Beatriz Monge-Sanz, Barbara Gabriella Renzi, and Giulio Napolitano. Linguistic analysis of ipcc summaries for policymakers and associated coverage. *Nature Climate Change*, 6(3):311–316, 2016.
- [BDT<sup>+</sup>22] Nick Ballou, Sebastian Deterding, April Tyack, Elisa D Mekler, Rafael A Calvo, Dorian Peters, Gabriela Villalobos-Zúñiga, and Selen Turkey. Self-determination theory in hci: shaping a research agenda. In *CHI conference on human factors in computing systems extended abstracts*, pages 1–6, 2022.
- [bea22] beatoven.ai. Royalty Free Music by Beatoven | Beatoven.ai, 2022.
- [BFvdL<sup>+</sup>20] Michael Blastland, Alexandra LJ Freeman, Sander van der Linden, Theresa M Marteau, and David Spiegelhalter. Five rules for evidence communication. *Nature*, 587(7834):362–364, 2020.
- [BHR<sup>+</sup>09] Joost Broekens, Marcel Heerink, Henk Rosendal, et al. Assistive social robots in elderly care: a review. *Gerontechnology*, 8(2):94–103, 2009.
- [BJ<sup>+</sup>08] Pamela Baxter, Susan Jack, et al. Qualitative case study methodology: Study design and implementation for novice researchers. *The qualitative report*, 13(4):544–559, 2008.
- [BKEE18] Ann L Butt, Suzan Kardong-Edgren, and Anthony Ellertson. Using game-based virtual reality with haptics for skill acquisition. *Clinical Simulation in Nursing*, 16:25–32, 2018.

- [Ble02] Blender Foundation. blender.org - Home of the Blender project - Free and Open 3D Creation Software, 2002.
- [Ble18] Eli Blevis. Seeing what is and what can be: On sustainability, respect for work, and design for respect. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, pages 1–14, 2018.
- [BLT<sup>+</sup>14] Marc Busch, Mario Lorenz, Manfred Tscheligi, Christina Hochleitner, and Trenton Schulz. Being there for real: presence in real and virtual environments and its relation to usability. In *Proceedings of the 8th nordic conference on human-computer interaction: fun, fast, foundational*, pages 117–126, 2014.
- [BM10] David Benyon and Oli Mival. From human-computer interactions to human-companion relationships. In *Proceedings of the first international conference on intelligent interactive technologies and multimedia*, pages 1–9, 2010.
- [BM21a] Emma Frances Bloomfield and Chris Manktelow. Climate communication and storytelling. *Climatic Change*, 167(3-4):34, 2021.
- [BM21b] Peter André Busch and Stephen McCarthy. Antecedents and consequences of problematic smartphone use: A systematic literature review of an emerging research area. *Computers in human behavior*, 114:106414, 2021.
- [BMA<sup>+</sup>19] Marie-Stéphanie Bracq, Estelle Michinov, Bruno Arnaldi, Benoît Caillaud, Bernard Gibaud, Valérie Gouranton, and Pierre Jannin. Learning procedural skills with a virtual reality simulator: An acceptability study. *Nurse education today*, 79:153–160, 2019.
- [BMK21] BMK. Austria’s 2030 Mobility Master Plan, 2021. publisher: Federal Ministry Republic of Austria for Climate Action, Environment, Energy, Mobility, Innovation and Technology.
- [BMLF<sup>+</sup>15] Joël Billieux, Pierre Maurage, Olatz Lopez-Fernandez, Daria J Kuss, and Mark D Griffiths. Can disordered mobile phone use be considered a behavioral addiction? an update on current evidence and a comprehensive model for future research. *Current Addiction Reports*, 2(2):156–162, 2015.
- [Bog10] Ian Bogost. *Persuasive games: The expressive power of videogames*. mit Press, 2010.
- [Bre03] Cynthia Breazeal. Toward sociable robots. *Robotics and autonomous systems*, 42(3-4):167–175, 2003.
- [Bro84] Richard D Brown. *Revolution in time: Clocks and the making of the modern world*, 1984.

- [Bro96] John Brooke. *SUS – a quick and dirty usability scale*, pages 189–194. 01 1996.
- [Bro09] Clint Brown. Bringing your geographic information to life. ESRI International User Conference, San Diego, Calif., July 13-17, 2009.
- [BSR<sup>+</sup>08] Michael Beetz, Freek Stulp, Bernd Radig, Jan Bandouch, Nico Blodow, Mihai Dolha, Andreas Fedrizzi, Dominik Jain, Uli Klank, Ingo Kresse, et al. The assistive kitchen—a demonstration scenario for cognitive technical systems. In *RO-MAN 2008-The 17th IEEE International Symposium on Robot and Human Interactive Communication*, pages 1–8. IEEE, 2008.
- [BV17] Mark Boukes and Rens Vliegthart. News consumption and its unpleasant side effect. *Journal of Media Psychology*, 2017.
- [BVA<sup>+</sup>] Thijs Bouman, Mark Verschoor, Casper J. Albers, Gisela Böhm, Stephen D. Fisher, Wouter Poortinga, Lorraine Whitmarsh, and Linda Steg. When worry about climate change leads to climate action: How values, worry and personal responsibility relate to various climate actions. 62:102061.
- [BVA<sup>+</sup>20] Thijs Bouman, Mark Verschoor, Casper J Albers, Gisela Böhm, Stephen D Fisher, Wouter Poortinga, Lorraine Whitmarsh, and Linda Steg. When worry about climate change leads to climate action: How values, worry and personal responsibility relate to various climate actions. *Global Environmental Change*, 62:102061, 2020.
- [BW17] Susanne Biundo and Andreas Wendemuth. An introduction to companion-technology. *Companion Technology: A Paradigm Shift in Human-Technology Interaction*, pages 1–15, 2017.
- [BZSP19] Michael Burmester, Katharina Zeiner, Katharina Schippert, and Axel Platz. Creating positive experiences with digital companions. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems*, pages 1–6, 2019.
- [Cal14] Gordon Calleja. Immersion in virtual worlds. *The Oxford handbook of virtuality*, pages 222–236, 2014.
- [Car17] Daniel W Carruth. Virtual reality for education and workforce training. In *2017 15th International Conference on Emerging eLearning Technologies and Applications (ICETA)*, pages 1–6. IEEE, 2017.
- [CBC<sup>+</sup>00] Justine Cassell, Tim Bickmore, Lee Campbell, Hannes Vilhjalmsson, Hao Yan, et al. Human conversation as a system framework: Designing embodied conversational agents. *Embodied conversational agents*, pages 29–63, 2000.

- [CBM<sup>+</sup>19] Astrid Carolus, Jens F Binder, Ricardo Muench, Catharina Schmidt, Florian Schneider, and Sarah L Buglass. Smartphones as digital companions: Characterizing the relationship between users and their phones. *New Media & Society*, 21(4):914–938, 2019.
- [CBN18] Allan Collins, John Seely Brown, and Susan E Newman. Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In *Knowing, learning, and instruction*, pages 453–494. Routledge, 2018.
- [CCB15] Marta E Cecchinato, Anna L Cox, and Jon Bird. Smartwatches: the good, the bad and the ugly? In *Proceedings of the 33rd Annual ACM Conference extended abstracts on human factors in computing systems*, pages 2133–2138, 2015.
- [CCMC20] Nicola Cellini, Natale Canale, Giovanna Mioni, and Sebastiano Costa. Changes in sleep pattern, sense of time and digital media use during covid-19 lockdown in italy. *Journal of sleep research*, 29(4):e13074, 2020.
- [CCT<sup>+</sup>18] Yuhang Che, Heather Culbertson, Chih-Wei Tang, Sudipto Aich, and Allison M. Okamura. Facilitating human-mobile robot communication via haptic feedback and gesture teleoperation. *ACM Transactions on Human-Robot Interaction*, 7(3):1–23, October 2018.
- [Cit95] City of Vienna. ViennaGIS, 1995. <https://www.wien.gv.at/viennagis/applikationen.html> [Accessed: 1 November 2023].
- [CLFH18] Ashley Colley, Aki Leinonen, Meri-Tuulia Forsman, and Jonna Häkkinä. Ems painter: Co-creating visual art using electrical muscle stimulation. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction*, pages 266–270, 2018.
- [CM03a] J. Casper and R.R. Murphy. Human-robot interactions during the robot-assisted urban search and rescue response at the world trade center. *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)*, 33(3):367–385, 2003.
- [CM03b] Stuart P Cottrell and Carolin Meisel. Predictors of personal responsibility to protect the marine environment among scuba divers. In *Proceedings of the 2003 northeastern recreation research symposium*, pages 252–261, 2003.
- [CMC00] Philip Cohen, David McGee, and Josh Clow. The Efficiency of Multimodal Interaction for a Map-based Task. In *Sixth Applied Natural Language Processing Conference*, pages 331–338, Seattle, Washington, USA, April 2000. Association for Computational Linguistics.

- [CMM10] George Chang, Patricia Morreale, and Padmavathi Medicherla. Applications of augmented reality systems in education. In *Society for Information Technology & Teacher Education International Conference*, pages 1380–1385. Association for the Advancement of Computing in Education (AACE), 2010.
- [CMO<sup>+</sup>99] Philip Cohen, David McGee, Sharon Oviatt, Lizhong Wu, Joshua Clow, Robert King, Simon Julier, and Lawrence Rosenblum. Multimodal Interaction for 2D and 3D Environments. *IEEE Computer Graphics and Applications*, 19:10–13, 1999.
- [Coo11] Caren B Cooper. Media literacy as a key strategy toward improving public acceptance of climate change science. *BioScience*, 61(3):231–237, 2011.
- [CR07] Luca Chittaro and Roberto Ranon. Web3d technologies in learning, education and training: Motivations, issues, opportunities. *Computers & Education*, 49(1):3–18, 2007.
- [CRCC14] Nancy A Cheever, Larry D Rosen, L Mark Carrier, and Amber Chavez. Out of sight is not out of mind: The impact of restricting wireless mobile device use on anxiety levels among low, moderate and high users. *Computers in Human Behavior*, 37:290–297, 2014.
- [CSB<sup>+</sup>14] Philippe Ciais, Christopher Sabine, Govindasamy Bala, Laurent Bopp, Victor Brovkin, Josep Canadell, Abha Chhabra, Ruth DeFries, James Galloway, Martin Heimann, et al. Carbon and other biogeochemical cycles. In *Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, pages 465–570. Cambridge University Press, 2014.
- [DAA15] Kadir Demirci, Mehmet Akgönül, and Abdullah Akpınar. Relationship of smartphone use severity with sleep quality, depression, and anxiety in university students. *Journal of behavioral addictions*, 4(2):85–92, 2015.
- [Dah10] Michael F Dahlstrom. The role of causality in information acceptance in narratives: An example from science communication. *Communication Research*, 37(6):857–875, 2010.
- [Dah12] Michael F Dahlstrom. The persuasive influence of narrative causality: Psychological mechanism, strength in overcoming resistance, and persistence over time. *Media Psychology*, 15(3):303–326, 2012.
- [Dah14] Michael F Dahlstrom. Using narratives and storytelling to communicate science with nonexpert audiences. *Proceedings of the national academy of sciences*, 111(supplement\_4):13614–13620, 2014.

- [Dan17] Kahneman Daniel. *Thinking, fast and slow*. 2017.
- [Dav89] Fred D Davis. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS quarterly*, pages 319–340, 1989.
- [Dav93] Fred D Davis. User acceptance of information technology: system characteristics, user perceptions and behavioral impacts. *International journal of man-machine studies*, 38(3):475–487, 1993.
- [DB09] Dimitrios Dakopoulos and Nikolaos G Bourbakis. Wearable obstacle avoidance electronic travel aids for blind: a survey. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)*, 40(1):25–35, 2009.
- [Dou01] Paul Dourish. *Where the action is: the foundations of embodied interaction*. MIT press, 2001.
- [Dou10] Paul Dourish. Hci and environmental sustainability: the politics of design and the design of politics. In *Proceedings of the 8th ACM conference on designing interactive systems*, pages 1–10, 2010.
- [DR08] Edward L Deci and Richard M Ryan. Self-determination theory: An approach to human motivation and personality. *University of Rochester, NY*, URL < <http://www.psych.rochester.edu/SDT/theory.html>, 2008.
- [DR13] Edward L Deci and Richard M Ryan. *Intrinsic motivation and self-determination in human behavior*. Springer Science & Business Media, 2013.
- [DSBG] Liesbeth De Schutter, Martin Bruckner, and Stefan Giljum. Achtung: Heiß und fettig—klima & ernährung in Österreich—auswirkungen der Österreichischen ernährung auf das klima. pages 58–59.
- [DW02] Joshua D Drake and John C Worsley. *Practical PostgreSQL*. " O'Reilly Media, Inc.", 2002.
- [DWK<sup>+</sup>05] Kerstin Dautenhahn, Sarah Woods, Christina Kaouri, Michael L Walters, Kheng Lee Koay, and Iain Werry. What is a robot companion-friend, assistant or butler? In *2005 IEEE/RSJ international conference on intelligent robots and systems*, pages 1192–1197. IEEE, 2005.
- [EEV<sup>+</sup>12] Anna Esposito, Antonietta M Esposito, Alessandro Vinciarelli, Rüdiger Hoffmann, and Vincent Müller. *Cognitive Behavioural Systems: COST 2102 International Training School, Dresden, Germany, February 21-26, 2011, Revised Selected Papers*, volume 7403. Springer, 2012.

- [EHO18] Ayaka Ebisu, Satoshi Hashizume, and Yoichi Ochiai. Building a feedback loop between electrical stimulation and percussion learning. In *ACM SIGGRAPH 2018 Studio*, pages 1–2. 2018.
- [EHS<sup>+</sup>17] Ayaka Ebisu, Satoshi Hashizume, Kenta Suzuki, Akira Ishii, Mose Sakashita, and Yoichi Ochiai. Stimulated percussions: Method to control human for learning music by using electrical muscle stimulation. In *Proceedings of the 8th Augmented Human International Conference*, pages 1–5, 2017.
- [End88] Mica R. Endsley. Design and evaluation for situation awareness enhancement. *Proceedings of the Human Factors Society Annual Meeting*, 32(2):97–101, October 1988.
- [END08] Jemma Edmunds, Nikos Ntoumanis, and Joan L Duda. Testing a self-determination theory-based teaching style intervention in the exercise domain. *European journal of social psychology*, 38(2):375–388, 2008.
- [End21] Mica R. Endsley. Situation Awareness. In *HANDBOOK OF HUMAN FACTORS AND ERGONOMICS*, pages 434–455. John Wiley & Sons, Ltd, 2021.
- [ERM18] Katharina Emmerich, Patrizia Ring, and Maic Masuch. I’m glad you are on my side: How to design compelling game companions. In *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play*, pages 141–152, 2018.
- [Eur21] European Commission, Eurostat. Daily calorie supply per capita by source, 2021.
- [FA77] Martin Fishbein and Icek Ajzen. Belief, attitude, intention, and behavior: An introduction to theory and research. 1977.
- [FAO21] FAO. *World Food and Agriculture – Statistical Yearbook 2021*. Food and Agriculture Organization of the United Nations, Rome, Italy, 2021. OCLC: 1285552192.
- [FAW19] Thomas Franke, Christiane Attig, and Daniel Wessel. A personal resource for technology interaction: development and validation of the affinity for technology interaction (ati) scale. *International Journal of Human-Computer Interaction*, 35(6):456–467, 2019.
- [FD06] Jodi Forlizzi and Carl DiSalvo. Service robots in the domestic environment: a study of the roomba vacuum in the home. In *Proceedings of the 1st ACM SIGCHI/SIGART conference on Human-robot interaction*, pages 258–265, 2006.

- [FDGT12] Michelle S Fortier, Joan L Duda, Eva Guerin, and Pedro J Teixeira. Promoting physical activity: development and testing of self-determination theory-based interventions. *International Journal of Behavioral Nutrition and Physical Activity*, 9:1–14, 2012.
- [FELC11] Elisa Frank, Hallie Eakin, and David López-Carr. Social identity, perception and motivation in adaptation to climate risk in the coffee sector of chiapas, mexico. *Global environmental change*, 21(1):66–76, 2011.
- [FFN<sup>+</sup>17] Ryohei Fushimi, Eisuke Fujinawa, Takuji Narumi, Tomohiro Tanikawa, and Michitaka Hirose. Vibrat-o-matic: Producing vocal vibrato using ems. In *Proceedings of the 8th Augmented Human International Conference*, pages 1–5, 2017.
- [FGA<sup>+</sup>18] Zhenan Feng, Vicente A González, Robert Amor, Ruggiero Lovreglio, and Guillermo Cabrera-Guerrero. Immersive virtual reality serious games for evacuation training and research: A systematic literature review. *Computers & Education*, 127:252–266, 2018.
- [FH19] Moira Fagan and Christine Huang. A look at how people around the world view climate change. 2019.
- [Fie02] Andy Field. How to design and report experiments. 2002.
- [Fis84] Walter R Fisher. Narration as a human communication paradigm: The case of public moral argument. *Communications Monographs*, 51(1):1–22, 1984.
- [FKHM<sup>+</sup>21] Anna Freytag, Katharina Knop-Huelss, Adrian Meier, Leonard Reinecke, Dorothee Hefner, Christoph Klimmt, and Peter Vorderer. Permanently online—always stressed out? the effects of permanent connectedness on stress experiences. *Human Communication Research*, 47(2):132–165, 2021.
- [FKS22] Sarah Faltaous, Marion Koelle, and Stefan Schneegass. From perception to action: a review and taxonomy on electrical muscle stimulation in hci. In *Proceedings of the 21st International Conference on Mobile and Ubiquitous Multimedia*, pages 159–171, 2022.
- [FKW04] Jacqueline Frick, Florian G Kaiser, and Mark Wilson. Environmental knowledge and conservation behavior: Exploring prevalence and structure in a representative sample. *Personality and Individual differences*, 37(8):1597–1613, 2004.
- [FNGS20] Sarah Faltaous, Joshua Neuwirth, Uwe Gruenefeld, and Stefan Schneegass. Savr: Increasing safety in virtual reality environments via electrical muscle stimulation. In *19th International Conference on Mobile and Ubiquitous Multimedia*, MUM 2020, page 254–258, 2020.

- [Fog02] Brian J Fogg. Persuasive technology: using computers to change what we think and do. *Ubiquity*, 2002(December):2, 2002.
- [For15] S Formica. Digital detox: 7 steps to find your inner balance. n/a: Sandro formica. 2015.
- [FS09] Stuart G Ferguson and Saul Shiffman. The relevance and treatment of cue-induced cravings in tobacco dependence. *Journal of substance abuse treatment*, 36(3):235–243, 2009.
- [FS11] Pinde Fu and Jiulin Sun. *Web GIS: Principles and Applications*. Esri Press, 2011.
- [Fue24] C. F. Fuechsel. Map, Mar 2024. <https://www.britannica.com/science/map> [Accessed: (15 April 2024)].
- [FWLR19] Anna-Katharina Frison, Philipp Wintersberger, Tianjia Liu, and Andreas Riener. Why do you like to drive automated? a context-dependent analysis of highly automated driving to elaborate requirements for intelligent user interfaces. In *Proceedings of the 24th international conference on intelligent user interfaces*, pages 528–537, 2019.
- [Gam01] Jeanne Gamble. Modelling the invisible: The pedagogy of craft apprenticeship. *Studies in continuing education*, 23(2):185–200, 2001.
- [GDSM20] Kimberly Garcia, Daniel David Schwyn, and Florian Michahelles. A digital companion for air travelers. In *22nd International Conference on Human-Computer Interaction with Mobile Devices and Services*, pages 1–6, 2020.
- [Gee03] James Paul Gee. What video games have to teach us about learning and literacy. *Computers in entertainment (CIE)*, 1(1):20–20, 2003.
- [Gee08] James Paul Gee. *Learning and games*. MacArthur Foundation Digital Media and Learning Initiative Chicago, IL, 2008.
- [GF16] Nitesh Goyal and Susan R Fussell. Effects of sensemaking translucence on distributed collaborative analysis. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing*, pages 288–302, 2016.
- [GGBZ21] Filip Górski, Damian Grajewski, Paweł Buń, and Przemysław Zawadzki. Study of interaction methods in virtual electrician training. *IEEE Access*, 9:118242–118252, 2021.
- [GGS09] Manuela Glaser, Bärbel Garsoffky, and Stephan Schwan. Narrative-based learning: Possible benefits and problems. 2009.

- [GHG<sup>+</sup>15] Michael Glodek, Frank Honold, Thomas Geier, Gerald Krell, Florian Nothdurft, Stephan Reuter, Felix Schüssel, Thilo Hörnle, Klaus Dietmayer, Wolfgang Minker, et al. Fusion paradigms in cognitive technical systems for human–computer interaction. *Neurocomputing*, 161:17–37, 2015.
- [GHJV09] Erich Gamma, Richard Helm, Ralph E. Johnson, and John Vlissides. *Design patterns: elements of reusable object-oriented software*. Addison-Wesley, Reading, MA, 2009. OCLC: 624525693.
- [GLAO23] Natalie Gold, Yiling Lin, Richard Ashcroft, and Magda Osman. ‘better off, as judged by themselves’: do people support nudges as a method to change their own behavior? *Behavioural Public Policy*, 7(1):25–54, 2023.
- [GLSG09] David Geronimo, Antonio M Lopez, Angel D Sappa, and Thorsten Graf. Survey of pedestrian detection for advanced driver assistance systems. *IEEE transactions on pattern analysis and machine intelligence*, 32(7):1239–1258, 2009.
- [GMRC20] Kimberly Garcia, Simon Mayer, Alessandro Ricci, and Andrei Ciortea. Proactive digital companions in pervasive hypermedia environments. In *2020 IEEE 6th International Conference on Collaboration and Internet Computing (CIC)*, pages 54–59. IEEE, 2020.
- [GMvO<sup>+</sup>18] Roxanne Gal, Anne M May, Elon J van Overmeeren, Monique Simons, and Evelyn M Monninkhof. The effect of physical activity interventions comprising wearables and smartphone applications on physical activity: a systematic review and meta-analysis. *Sports medicine-open*, 4:1–15, 2018.
- [God14] Godot Engine. Godot Engine - Free and open source 2D and 3D game engine, 2014.
- [God23] Godot Engine. Singletons (Autoload), 2023.
- [Gra14] Lindsay Grace. Adapting games from literature: game verbs for player behavior. In *CHI’14 Extended Abstracts on Human Factors in Computing Systems*, pages 423–426. 2014.
- [GRS<sup>+</sup>19] Fiona B Gillison, Peter Rouse, Martyn Standage, Simon J Sebire, and Richard M Ryan. A meta-analysis of techniques to promote motivation for health behaviour change from a self-determination theory perspective. *Health psychology review*, 13(1):110–130, 2019.
- [Gru18] Jonathan Grudin. From tool to partner: The evolution of human-computer interaction. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*, pages 1–3, 2018.

- [GVM24] Kimberly Garcia, Jonathan Vontobel, and Simon Mayer. A digital companion architecture for ambient intelligence. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, 8(2):1–26, 2024.
- [GVR<sup>+</sup>10] Ashok Goel, Swaroop Vattam, Spencer Rugaber, David Joyner, Cindy Hmelo-Silver, Rebecca Jordan, Sameer Honwad, Steven Gray, and Suparna Sinha. Learning functional and causal abstractions of classroom aquaria. In *Proceedings of the Annual Meeting of the Cognitive Science Society*, volume 32, 2010.
- [GZ09] Sylvia Gaul and Martina Ziefle. Smart home technologies: Insights into generation-specific acceptance motives. In *HCI and Usability for e-Inclusion: 5th Symposium of the Workgroup Human-Computer Interaction and Usability Engineering of the Austrian Computer Society, USAB 2009, Linz, Austria, November 9-10, 2009 Proceedings 5*, pages 312–332. Springer, 2009.
- [Hai01] D. W. Hainsworth. Teleoperation User Interfaces for Mining Robotics. *Autonomous Robots*, 11(1):19–28, July 2001.
- [Has10] Marc Hassenzahl. *Experience design: Technology for all the right reasons*, volume 8. Morgan & Claypool Publishers, 2010.
- [HBDH<sup>+</sup>16] Antje Hebestreit, Gianvincenzo Barba, Stefaan De Henauw, Gabriele Eiben, Charalampos Hadjigeorgiou, Éva Kovács, Vittorio Krogh, Luis A. Moreno, Valeria Pala, Toomas Veidebaum, Maïke Wolters, and Claudia Börnhorst. Cross-sectional and longitudinal associations between energy intake and BMI z-score in European children. *International Journal of Behavioral Nutrition and Physical Activity*, 13(1):23, December 2016.
- [HBMH01] Marcel Hunecke, Anke Blöbaum, Ellen Matthies, and Rainer Höger. Responsibility and environment: Ecological norm orientation and external factors in the domain of travel mode choice behavior. *Environment and behavior*, 33(6):830–852, 2001.
- [HCK<sup>+</sup>15] Severin Haug, Raquel Paz Castro, Min Kwon, Andreas Filler, Tobias Kowatsch, and Michael P Schaub. Smartphone use and smartphone addiction among young people in switzerland. *Journal of behavioral addictions*, 4(4):299–307, 2015.
- [HDG10] Marc Hassenzahl, Sarah Diefenbach, and Anja Göritz. Needs, affect, and interactive products—facets of user experience. *Interacting with computers*, 22(5):353–362, 2010.
- [HDW<sup>+</sup>17] Mahmoud Hassan, Florian Daiber, Frederik Wiehr, Felix Kosmalla, and Antonio Krüger. Footstriker: An ems-based foot strike assistant for

- running. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, 1(1):1–18, 2017.
- [Hea91] HM Hearnshaw. What is the user’s mental model of gis. *Proceedings of EGIS’91*, 1:427–436, 1991.
- [HHKK16] Alexis Hiniker, Sungsoo Hong, Tadayoshi Kohno, and Julie A Kientz. Mytime: designing and evaluating an intervention for smartphone non-use. In *Proceedings of the 2016 CHI conference on human factors in computing systems*, pages 4746–4757, 2016.
- [HHT87] Jody M Hines, Harold R Hungerford, and Audrey N Tomera. Analysis and synthesis of research on responsible environmental behavior: A meta-analysis. *The Journal of environmental education*, 18(2):1–8, 1987.
- [Hin02] Geoffrey Hinchliffe. Situating skills. *Journal of philosophy of education*, 36(2):187–205, 2002.
- [HK17] Juho Hamari and Lauri Keronen. Why do people play games? a meta-analysis. *International Journal of Information Management*, 37(3):125–141, 2017.
- [HLSC20] Jordan Harold, Irene Lorenzoni, Thomas F Shipley, and Kenny R Coventry. Communication of ipcc visuals: Ipcc authors’ views and assessments of visual complexity. *Climatic Change*, 158(2):255–270, 2020.
- [HMCA23] Patrick Hartmann, Aitor Marcos, Juana Castro, and Vanessa Apaolaza. Perspectives: Advertising and climate change—part of the problem or part of the solution? *International Journal of Advertising*, 42(2):430–457, 2023.
- [Hog01] Eileen A Hogan. The attention economy: understanding the new currency of business, 2001.
- [HOM<sup>+</sup>13] Atsushi Hiyama, Hiroyuki Onimaru, Mariko Miyashita, Eikan Ebuchi, Masazumi Seki, and Michitaka Hirose. Augmented reality system for measuring and learning tacit artisan skills. In *International Conference on Human Interface and the Management of Information*, pages 85–91. Springer, 2013.
- [How17] Candice Howarth. Informing decision making on climate change and low carbon futures: Framing narratives around the united kingdom’s fifth carbon budget. *Energy research & social science*, 31:295–302, 2017.
- [HPPS11] Karen Henwood, Nick Pidgeon, Karen Parkhill, and Peter Simmons. Researching risk: Narrative, biography, subjectivity. *Historical Social Research/Historische Sozialforschung*, pages 251–272, 2011.

- [HPS<sup>+</sup>17] Mariam Hassib, Max Pfeiffer, Stefan Schneegass, Michael Rohs, and Florian Alt. Emotion actuator: Embodied emotional feedback through electroencephalography and electrical muscle stimulation. In *Proceedings of the 2017 chi conference on human factors in computing systems*, pages 6133–6146, 2017.
- [HRP20] E Rafael Hernández-Ríos and Christian Penalzoa. Human-to-human knowledge transfer using functional electrical stimulation. In *2020 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, pages 3788–3792. IEEE, 2020.
- [HS88] Sandra G. Hart and Lowell E. Staveland. Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In *P. A. Hancock and N. Meshkati (Eds.) Human Mental Workload*. Amsterdam: North Holland Press, 1988.
- [HS08] Kami Hanson and Brett E Shelton. Design and development of virtual reality: analysis of challenges faced by educators. *Journal of Educational Technology & Society*, 11(1):118–131, 2008.
- [HS20] Luke Haliburton and Albrecht Schmidt. Technologies for healthy work. *Interactions*, 27(3):64–66, 2020.
- [HSML07] Cindy E Hmelo-Silver, Surabhi Marathe, and Lei Liu. Fish swim, rocks sit, and lungs breathe: Expert-novice understanding of complex systems. *The Journal of the Learning Sciences*, 16(3):307–331, 2007.
- [HSMLC20] Inez EP Harker-Schuch, Franklin P Mills, Steven J Lade, and Rebecca M Colvin. Co2peration—structuring a 3d interactive digital game to improve climate literacy in the 12-13-year-old age group. *Computers & Education*, 144:103705, 2020.
- [HST19] Li-Hsing Ho, Hung Sun, and Tsun-Hung Tsai. Research on 3d painting in virtual reality to improve students’ motivation of 3d animation learning. *Sustainability*, 11(6):1605, 2019.
- [HSW12] Frank Honold, Felix Schüssel, and Michael Weber. Adaptive probabilistic fission for multimodal systems. In *Proceedings of the 24th Australian Computer-Human Interaction Conference*, pages 222–231, 2012.
- [HvdLC12] Jennifer Helgeson, Sander van der Linden, and Ilan Chabay. The role of knowledge, learning and mental models in public perceptions of climate change related risks. *Learning for sustainability in times of accelerating change*, pages 329–346, 2012.
- [HYWTZ01] Huosheng Hu, Lixiang Yu, Pui Wo Tsui, and Quan Zhou. Internet-based robotic systems for teleoperation. *Assembly Automation*, 21(2):143–152, January 2001. Publisher: MCB UP Ltd.

- [HZ08] Mordechai Muki Haklay and Antigoni Zafiri. Usability engineering for GIS: Learning from a screenshot. *Cartographic Journal*, 45:87–97, 2008.
- [IIM<sup>+</sup>16] Misaki Iyobe, Tomoyuki Ishida, Akihiro Miyakawa, Noriki Uchida, Kaoru Sugita, and Yoshitaka Shibata. Development of a mobile virtual traditional crafting presentation system using augmented reality technology. *International Journal of Space-Based and Situated Computing*, 6(4):239–251, 2016.
- [Inc16] Frank P Incropera. *Climate change: a wicked problem: complexity and uncertainty at the intersection of science, economics, politics, and human behavior*. Cambridge University Press, 2016.
- [ISO14] Geographic information — Reference model — Part 1: Fundamentals. Standard, International Organization for Standardization, Geneva, CH, November 2014.
- [Jan20] Shamila Janakiraman. Digital games for environmental sustainability education: Implications for educators. In *Eighth International Conference on Technological Ecosystems for Enhancing Multiculturality*, pages 542–545, 2020.
- [JAS22] JASP Team. JASP (Version 0.16.3)[Computer software], 2022.
- [JB04] Michael Johnston and Srinivas Bangalore. MATCHkiosk: A Multimodal Interactive City Guide. In *Proceedings of the ACL Interactive Poster and Demonstration Sessions*, pages 222–225, Barcelona, Spain, July 2004. Association for Computational Linguistics.
- [JBVB17] Cheryl I Johnson, Shannon KT Bailey, and Wendi L Van Buskirk. Designing effective feedback messages in serious games and simulations: A research review. *Instructional techniques to facilitate learning and motivation of serious games*, pages 119–140, 2017.
- [JCM<sup>+</sup>97] Michael Johnston, Philip R. Cohen, David McGee, Sharon L. Oviatt, James A. Pittman, and Ira Smith. Unification-based Multimodal Integration. In *35th Annual Meeting of the Association for Computational Linguistics and 8th Conference of the European Chapter of the Association for Computational Linguistics*, pages 281–288, Madrid, Spain, July 1997. Association for Computational Linguistics.
- [JFHZ05] Nassim Jafarinaimi, Jodi Forlizzi, Amy Hurst, and John Zimmerman. Breakaway: an ambient display designed to change human behavior. In *CHI'05 extended abstracts on Human factors in computing systems*, pages 1945–1948, 2005.

- [JK18] Lasse Jensen and Flemming Konradsen. A review of the use of virtual reality head-mounted displays in education and training. *Education and Information Technologies*, 23:1515–1529, 2018.
- [JKC16] Yoonhyuk Jung, Seongcheol Kim, and Boreum Choi. Consumer valuation of the wearables: The case of smartwatches. *Computers in Human Behavior*, 63:899–905, 2016.
- [JL19] Monika Jingar and Helena Lindgren. Tangible communication of emotions with a digital companion for managing stress: an exploratory co-design study. In *Proceedings of the 7th International Conference on Human-Agent Interaction*, pages 28–36, 2019.
- [JP17] Michael D Jones and Holly Peterson. Narrative persuasion and storytelling as climate communication strategies. In *Oxford Research Encyclopedia of Climate Science*. 2017.
- [JSB17] Shubham Jain, Shubham Sharma, and Dhawal Babbar. Star-force: A playful implementation of the jedi-force. In *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction*, pages 761–766, 2017.
- [JSH11] Farrokh Janabi-Sharifi and Iraj Hassanzadeh. Experimental analysis of mobile-robot teleoperation via shared impedance control. *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)*, 41(2):591–606, 2011.
- [KA02] Anja Kollmuss and Julian Agyeman. Mind the gap: why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental education research*, 8(3):239–260, 2002.
- [KAH18] Jarrod Knibbe, Adrian Alsmith, and Kasper Hornbæk. Experiencing electrical muscle stimulation. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, 2(3):1–14, 2018.
- [KBP07] Ashish Kapoor, Winslow Burleson, and Rosalind W Picard. Automatic prediction of frustration. *International journal of human-computer studies*, 65(8):724–736, 2007.
- [KDV11] Erik Knol and Peter W De Vries. Enercities—a serious game to stimulate sustainability and energy conservation: Preliminary results. *eLearning Papers*, (25), 2011.
- [KG11] Daria J Kuss and Mark D Griffiths. Online social networking and addiction—a review of the psychological literature. *International journal of environmental research and public health*, 8(9):3528–3552, 2011.

- [KGJ18] Songhyun Kim, Junseok Goh, and Soojin Jun. The use of voice input to induce human communication with banking chatbots. In *Companion of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*, HRI '18, page 151–152, New York, NY, USA, 2018. Association for Computing Machinery.
- [KHF<sup>+</sup>19] Julian Kreimeier, Sebastian Hammer, Daniel Friedmann, Pascal Karg, Clemens Bühner, Lukas Bankel, and Timo Götzelmann. Evaluation of different types of haptic feedback influencing the task-based presence and performance in virtual reality. In *Proceedings of the 12th ACM International Conference on PErvasive Technologies Related to Assistive Environments*, pages 289–298, 2019.
- [KHY<sup>+</sup>19] Mareike Kritzler, Jack Hodges, Dan Yu, Kimberly Garcia, Hemant Shukla, and Florian Michahelles. Digital companion for industry. In *Companion Proceedings of The 2019 World Wide Web Conference*, pages 663–667, 2019.
- [KIMR18] Michinari Kono, Yoshio Ishiguro, Takashi Miyaki, and Jun Rekimoto. Design and study of a multi-channel electrical muscle stimulation toolkit for human augmentation. In *Proceedings of the 9th Augmented Human International Conference*, pages 1–8, 2018.
- [KJH10] Jitka Komárková, Martin Jedlicka, and Miloslav Hub. Usability user testing of selected web-based GIS applications. *WSEAS Transactions on Computers*, 9:21–30, 01 2010.
- [KJKL19] Jaejeung Kim, Hayoung Jung, Minsam Ko, and Uichin Lee. Goalkeeper: exploring interaction lockout mechanisms for regulating smartphone use. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, 3(1):1–29, 2019.
- [KKC<sup>+</sup>20] Sabine U König, Ashima Keshava, Viviane Clay, Kirsten Rittershofer, Nicolas Kuske, and Peter König. Embodied spatial knowledge acquisition in immersive virtual reality: Comparison to map exploration. *bioRxiv*, pages 2020–01, 2020.
- [KKYS02] N. Krahnstoever, S. Kettebekov, M. Yeasin, and R. Sharma. A real-time framework for natural multimodal interaction with large screen displays. In *Proceedings - 4th IEEE International Conference on Multimodal Interfaces, ICMI 2002*, pages 349–354. Institute of Electrical and Electronics Engineers Inc., 2002.
- [KM15] Korina Katsaliaki and Navonil Mustafee. Edutainment for sustainable development: A survey of games in the field. *Simulation & Gaming*, 46(6):647–672, 2015.

- [KN19] Jarim Kim and Xiaoli Nan. Temporal framing effects differ for narrative versus non-narrative messages: The case of promoting hpv vaccination. *Communication research*, 46(3):401–417, 2019.
- [KNB<sup>+</sup>19] Seokbin Kang, Leyla Norooz, Elizabeth Bonsignore, Virginia Byrne, Tamara Clegg, and Jon E Froehlich. Prototypar: Prototyping and simulating complex systems with paper craft and augmented reality. In *Proceedings of the 18th ACM International Conference on Interaction Design and Children*, pages 253–266, 2019.
- [KNL19a] Shunichi Kasahara, Jun Nishida, and Pedro Lopes. Preemptive Action: Accelerating Human Reaction using Electrical Muscle Stimulation Without Compromising Agency. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, CHI '19, pages 1–15, New York, NY, USA, May 2019. Association for Computing Machinery.
- [KNL19b] Shunichi Kasahara, Jun Nishida, and Pedro Lopes. Preemptive action: Accelerating human reaction using electrical muscle stimulation without compromising agency. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, pages 1–15, 2019.
- [KPV19] Eric Krokos, Catherine Plaisant, and Amitabh Varshney. Virtual memory palaces: immersion aids recall. *Virtual reality*, 23:1–15, 2019.
- [KRC11] Wasim Ahmed Khan, Abdul Raouf, and Kai Cheng. Augmented reality for manufacturing. In *Virtual Manufacturing*, pages 1–56. Springer, 2011.
- [KRHB99] Florian G Kaiser, Michael Ranney, Terry Hartig, and Peter A Bowler. Ecological behavior, environmental attitude, and feelings of responsibility for the environment. *European psychologist*, 4(2):59, 1999.
- [KS84] Gerhard Kiefer and Herbert Schmolke. *VDE 0100 und die Praxis*. vde-Verlag Berlin-Offenbach, 1984.
- [KS20] Tomoyuki Kino and Kuniyasu Saigusa. Clinical safety of early rehabilitation using electrical muscle stimulation for patients with intracranial hypertension. *Medical Research Archives*, 8(7), 2020.
- [KST15] Tomoya Kitamura, Sho Sakaino, and Toshiaki Tsuji. Bilateral control using functional electrical stimulation. In *IECON 2015 - 41st Annual Conference of the IEEE Industrial Electronics Society*, pages 002336–002341, November 2015.
- [KUWM22] Khaled Kassem, Tobias Ungerböck, Philipp Wintersberger, and Florian Michahelles. What is happening behind the wall? towards a better understanding of a hidden robot’s intent by multimodal cues. *Proc. ACM Hum.-Comput. Interact.*, 6(MHCI), sep 2022.

- [KWB18] Geza Kovacs, Zhengxuan Wu, and Michael S Bernstein. Rotating online behavior change interventions increases effectiveness but also increases attrition. *Proceedings of the ACM on Human-Computer Interaction*, 2(CSCW):1–25, 2018.
- [KYA22] Rohit Ashok Khot, Jung-Ying Yi, and Deepti Aggarwal. Designing for microbreaks: Unpacking the design journey of zenscape. In *Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction*, pages 1–16, 2022.
- [KYL<sup>+</sup>15] Minsam Ko, Subin Yang, Joonwon Lee, Christian Heizmann, Jinyoung Jeong, Uichin Lee, Daehee Shin, Koji Yatani, Junehwa Song, and Kyong-Mee Chung. Nugu: a group-based intervention app for improving self-regulation of limiting smartphone use. In *Proceedings of the 18th ACM conference on computer supported cooperative work & social computing*, pages 1235–1245, 2015.
- [LAD<sup>+</sup>] Petros Lameris, Sylvester Arnab, Ian Dunwell, Craig Stewart, Samantha Clarke, and Panagiotis Petridis. Essential features of serious games design in higher education: Linking learning attributes to game mechanics: Essential features of serious games design. 48(4):972–994.
- [LB13] Pedro Lopes and Patrick Baudisch. Muscle-propelled force feedback: Bringing force feedback to mobile devices. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '13, page 2577–2580, 2013.
- [LB17a] Pedro Lopes and Patrick Baudisch. Immense power in a tiny package: Wearables based on electrical muscle stimulation. *IEEE Pervasive Computing*, 16(3):12–16, 2017.
- [LB17b] Pedro Lopes and Patrick Baudisch. Interactive systems based on electrical muscle stimulation. *Computer*, 50(10):28–35, 2017.
- [LB20] Kevin Lu and Aarnout Brombacher. Haptic feedback in running: Is it possible for information transfer through electrical muscle signalling? In *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction*, pages 479–485, 2020.
- [LBG13] Markus Löchtefeld, Matthias Böhmer, and Lyubomir Ganev. Appdetox: helping users with mobile app addiction. In *Proceedings of the 12th international conference on mobile and ubiquitous multimedia*, pages 1–2, 2013.
- [LBNH20] Matthias Laschke, Christoph Braun, Robin Neuhaus, and Marc Hassenzahl. Meaningful technology at work—a reflective design case of improving radiologists’ wellbeing through medical technology. In *Proceedings of the*

- 2020 *CHI Conference on Human Factors in Computing Systems*, pages 1–12, 2020.
- [LBR<sup>+</sup>15] Mario Lorenz, Marc Busch, Loukas Rentzos, Manfred Tscheligi, Philipp Klimant, and Peter Fröhlich. I’m there! the influence of virtual reality and mixed reality environments combined with two different navigation methods on presence. In *2015 IEEE Virtual Reality (VR)*, pages 223–224. IEEE, 2015.
- [LC93] V.J. Lumelsky and E. Cheung. Real-time collision avoidance in teleoperated whole-sensitive robot arm manipulators. *IEEE Transactions on Systems, Man, and Cybernetics*, 23(1):194–203, January 1993.
- [LCBA12] Kelly Levin, Benjamin Cashore, Steven Bernstein, and Graeme Auld. Overcoming the tragedy of super wicked problems: constraining our future selves to ameliorate global climate change. *Policy sciences*, 45(2):123–152, 2012.
- [LCD<sup>+</sup>24] H. Lee, K. Calvin, D. Dasgupta, G. Krinner, A. Mukherji, P. Thorne, and A. C. ... Ruane. Climate change 2023 synthesis report summary for policymakers. Technical report, CLIMATE CHANGE 2023 Synthesis Report: Summary for Policymakers, 2024.
- [LDR<sup>+</sup>21] Ruggiero Lovreglio, Xinyue Duan, Anass Rahouti, Robyn Phipps, and Daniel Nilsson. Comparing the effectiveness of fire extinguisher virtual reality and video training. *Virtual Reality*, 25(1):133–145, 2021.
- [LDV11] Songnian Li, Suzana Dragicevic, and Bert Veenendaal. *Advances in Web-based GIS, Mapping Services and Applications*. CRC Pr I Llc, 2011.
- [Lee12] Kangdon Lee. Augmented reality in education and training. *TechTrends*, 56(2):13–21, 2012.
- [Lee19] Jin-Ting Lee. Book review: designing and conducting mixed methods research, 2019.
- [LFH17] Jonathan Lazar, Jinjuan Heidi Feng, and Harry Hochheiser. *Research methods in human-computer interaction*. Morgan Kaufmann, 2017.
- [LHS08] Bettina Laugwitz, Theo Held, and Martin Schrepp. Construction and evaluation of a user experience questionnaire. volume 5298, pages 63–76, 11 2008.
- [LIB15] Pedro Lopes, Alexandra Ion, and Patrick Baudisch. Impacto: Simulating physical impact by combining tactile stimulation with electrical muscle stimulation. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology*, pages 11–19, 2015.

- [LIM<sup>+</sup>15] Pedro Lopes, Alexandra Ion, Willi Mueller, Daniel Hoffmann, Patrik Jonell, and Patrick Baudisch. Proprioceptive interaction. In *Proceedings of the 33rd annual acm conference on human factors in computing systems*, pages 939–948, 2015.
- [LJB15a] Pedro Lopes, Patrik Jonell, and Patrick Baudisch. Affordance++: Allowing objects to communicate dynamic use. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, CHI '15, page 2515–2524, 2015.
- [LJB15b] Pedro Lopes, Patrik Jonell, and Patrick Baudisch. Affordance++ allowing objects to communicate dynamic use. In *Proceedings of the 33rd annual acm conference on human factors in computing systems*, pages 2515–2524, 2015.
- [LLG14] Arlene R Lundquist, Emily J Lefebvre, and Sara J Garramone. Smartphones: Fulfilling the need for immediacy in everyday life, but at what cost. *International Journal of Humanities and Social Science*, 4(2):80–89, 2014.
- [LLS<sup>+</sup>19] Ulrik Lyngs, Kai Lukoff, Petr Slovak, Reuben Binns, Adam Slack, Michael Inzlicht, Max Van Kleek, and Nigel Shadbolt. Self-control in cyberspace: Applying dual systems theory to a review of digital self-control tools. In *proceedings of the 2019 CHI conference on human factors in computing systems*, pages 1–18, 2019.
- [LMBH23] Martin Valdemar Anker Lindrup, Arjun Rajendran Menon, and Aksel Biørn-Hansen. Carbon scales: Collective sense-making of carbon emissions from food production through physical data representation. In *Proceedings of the 2023 ACM Designing Interactive Systems Conference*, pages 1515–1530, 2023.
- [LMR<sup>+</sup>20] Anthony Leiserowitz, Edward Maibach, Seth Rosenthal, John Kotcher, Parrish Bergquist, Matthew T Ballew, Matthew H Goldberg, and Abel Gustafson. Climate change in the american mind: November 2019. 2020.
- [LN23] Zhenlong Li and Huan Ning. Autonomous GIS: the next-generation AI-powered GIS, 2023.
- [LQB16] Frieder Loch, Fabian Quint, and Iuliia Brishtel. Comparing video and augmented reality assistance in manual assembly. In *2016 12th International Conference on Intelligent Environments (IE)*, pages 147–150, 2016.
- [LSE21] Jong Ho Lee, Jessica Schroeder, and Daniel A Epstein. Understanding and supporting self-tracking app selection. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, 5(4):1–25, 2021.

- [LSGT12] Georgia Liarakou, Eleni Sakka, Costas Gavrilakis, and Costas Tsolakidis. Evaluation of serious games, as a tool for education for sustainable development. *European Journal of Open, Distance and E-learning*, 15(2), 2012.
- [LTR<sup>+</sup>23] Martin Valdemar Anker Lindrup, Jakob Tholander, Chiara Rossitto, Rob Comber, and Mattias Jacobsson. Designing for digital environmental stewardship in waste management. In *Proceedings of the 2023 ACM Designing Interactive Systems Conference*, pages 1581–1594, 2023.
- [Lup21] Ludmila Lupinacci. ‘absentmindedly scrolling through nothing’: liveness and compulsory continuous connectedness in social media. *Media, Culture & Society*, 43(2):273–290, 2021.
- [LVJPW10] Phillippa Lally, Cornelia HM Van Jaarsveld, Henry WW Potts, and Jane Wardle. How are habits formed: Modelling habit formation in the real world. *European journal of social psychology*, 40(6):998–1009, 2010.
- [LYC<sup>+</sup>17a] Pedro Lopes, Sijing You, Lung-Pan Cheng, Sebastian Marwecki, and Patrick Baudisch. Providing haptics to walls & heavy objects in virtual reality by means of electrical muscle stimulation. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, CHI ’17, page 1471–1482, 2017.
- [LYC<sup>+</sup>17b] Pedro Lopes, Sijing You, Lung-Pan Cheng, Sebastian Marwecki, and Patrick Baudisch. Providing haptics to walls & heavy objects in virtual reality by means of electrical muscle stimulation. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, pages 1471–1482, 2017.
- [LYGB16] Pedro Lopes, Doña Yüksel, François Guimbretière, and Patrick Baudisch. Muscle-plotter: An interactive system based on electrical muscle stimulation that produces spatial output. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology*, pages 207–217, 2016.
- [LYIB18] Pedro Lopes, Sijing You, Alexandra Ion, and Patrick Baudisch. Adding force feedback to mixed reality experiences and games using electrical muscle stimulation. In *Proceedings of the 2018 chi conference on human factors in computing systems*, pages 1–13, 2018.
- [MA] Konstantin Mitgutsch and Narda Alvarado. Purposeful by design?: a serious game design assessment framework. In *Proceedings of the International Conference on the Foundations of Digital Games*, pages 121–128. ACM.

- [May00] P Mayring. Qualitative inhaltsanalyse. forum qualita tive sozialforschung 1 (2), 2000.
- [MBGM19] Guido Makransky, Stefan Borre-Gude, and Richard E Mayer. Motivational and cognitive benefits of training in immersive virtual reality based on multiple assessments. *Journal of Computer Assisted Learning*, 35(6):691–707, 2019.
- [MBL<sup>+</sup>17] Donald McMillan, Barry Brown, Airi Lampinen, Moira McGregor, Eve Hoggan, and Stefania Pizza. Situating wearables: Smartwatch use in context. In *Proceedings of the 2017 chi conference on human factors in computing systems*, pages 3582–3594, 2017.
- [MBS<sup>+</sup>15] Christian Montag, Konrad Błaszkiwicz, Rayna Sariyska, Bernd Lachmann, Ionut Andone, Boris Trendafilov, Mark Eibes, and Alexander Markowetz. Smartphone usage in the 21st century: who is active on whatsapp? *BMC research notes*, 8(1):1–6, 2015.
- [MCC<sup>+</sup>19] Brandi S Morris, Polymeros Chrysochou, Jacob Dalgaard Christensen, Jacob L Orquin, Jorge Barraza, Paul J Zak, and Panagiotis Mitkidis. Stories vs. facts: triggering emotion and action-taking on climate change. *Climatic change*, 154:19–36, 2019.
- [McG19] M McGinn. ’s biggest pop-culture trend was climate anxiety. *Grist magazine*, 2019.
- [MCM17] Susana Martinez-Conde and Stephen L Macknik. Finding the plot in science storytelling in hopes of enhancing science communication. *Proceedings of the National Academy of Sciences*, 114(31):8127–8129, 2017.
- [MCS<sup>+</sup>21] Stijn AA Massar, Xin Yu Chua, Chun Siong Soon, Alyssa SC Ng, Ju Lynn Ong, Nicholas IYN Chee, Tih Shih Lee, Arko Ghosh, and Michael WL Chee. Trait-like nocturnal sleep behavior identified by combining wearable, phone-use, and self-report data. *NPJ digital medicine*, 4(1):90, 2021.
- [MD11] Susanne C Moser and Lisa Dilling. Communicating change science:-closing action climate. *The Oxford handbook of climate change and society*, page 161, 2011.
- [MDROS18] Jeremy Marty-Dugas, Brandon CW Ralph, Jonathan M Oakman, and Daniel Smilek. The relation between smartphone use and everyday inattention. *Psychology of Consciousness: Theory, Research, and Practice*, 5(1):46, 2018.
- [ME14] Melissa Mazmanian and Ingrid Erickson. The product of availability: understanding the economic underpinnings of constant connectivity. In *Proceedings of the SIGCHI conference on human factors in computing systems*, pages 763–772, 2014.

- [MEG<sup>+</sup>04] JT Matthews, SJ Engberg, J Glover, M Pollack, and S Thrun. Robotic assistants for the elderly: Designing and conducting field studies. In *Proceedings of ICRA*, 2004.
- [MF11] Alexey Melnikov and Ian Fette. The WebSocket Protocol. RFC 6455, December 2011.
- [MFB<sup>+</sup>23] Vikram Mohanty, Alexandre LS Filipowicz, Nayeli Suseth Bravo, Scott Carter, and David A Shamma. Save a tree or 6 kg of co2? understanding effective carbon footprint interventions for eco-friendly vehicular choices. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, pages 1–24, 2023.
- [MHZ<sup>+</sup>19] Xi Mei, Zhenyu Hu, Dongsheng Zhou, Qi Zhou, Xingxing Li, Xiaojia Wang, and Pan Jing. Sleep patterns, mobile phone use and psychological symptoms among adolescents in coastal developed city of china: an exploratory cross-sectional study. *Sleep and Biological Rhythms*, 17:233–241, 2019.
- [Mil23] Stuart Mills. Nudge/sludge symmetry: on the relationship between nudge and sludge and the resulting ontological, normative and transparency implications. *Behavioural Public Policy*, 7(2):309–332, 2023.
- [Mir91] Philip H Mirvis. *Flow: The psychology of optimal experience*, 1991.
- [MMKM17] Ezekiel Kuria Mwangi, Agnes Mindila, Stephen Kimani, and Agness Mindila. A Review Of Web-Based GIS Usability Elements. *Journal of Information Technology*, 4, 2017.
- [MMP<sup>+</sup>21] Junko Mochizuki, Piotr Magnuszewski, Michal Pajak, Karolina Krolkowska, Lukasz Jarzabek, and Michalina Kulakowska. Simulation games as a catalyst for social learning: The case of the water-food-energy nexus game. *Global Environmental Change*, 66:102204, 2021.
- [MN99] Stella Mills and Jan Noyes. Virtual reality: an overview of user-related design issues revised paper for special issue on “virtual reality: User issues” in interacting with computers, may 1998. *Interacting with computers*, 11(4):375–386, 1999.
- [MNU23] Isaac Makosa, Clemens Nuunyango, and Kingsley Chidozie Uchezuba. Build a smart sustainable windhoek: An ar game. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems*, pages 1–5, 2023.
- [MPC<sup>+</sup>17] Luca Morganti, Federica Pallavicini, Elena Cadel, Antonio Candelieri, Francesco Archetti, and Fabrizia Mantovani. Gaming for earth: Serious

- games and gamification to engage consumers in pro-environmental behaviours for energy efficiency. *Energy Research & Social Science*, 29:95–102, 2017.
- [MPGK15] Annette Mossel, Andreas Peer, Johannes Göllner, and Hannes Kaufmann. Towards an immersive virtual reality training system for cbrn disaster preparedness. In *The 12th International Multidisciplinary Modeling & Simulation Multiconference*. DIME University of Genoa, DIMEH University of Calabria, 2015.
- [MPO<sup>+</sup>19] Martha C Monroe, Richard R Plate, Annie Oxarart, Alison Bowers, and Willandia A Chaves. Identifying effective climate change education strategies: A systematic review of the research. *Environmental Education Research*, 25(6):791–812, 2019.
- [MPS<sup>+</sup>20] J Madden, S Pandita, JP Schuldt, B Kim, A S. Won, and NG Holmes. Ready student one: Exploring the predictors of student learning in virtual reality. *PloS one*, 15(3):e0229788, 2020.
- [MPSS09] Nicolas F Meuleau, Christian J Plaunt, David E Smith, and Tristan B Smith. An emergency landing planner for damaged aircraft. In *Twenty-First IAAI Conference*, 2009.
- [MPV<sup>+</sup>16] Abhinav Mehrotra, Veljko Pejovic, Jo Vermeulen, Robert Hendley, and Mirco Musolesi. My phone and me: understanding people’s receptivity to mobile notifications. In *Proceedings of the 2016 CHI conference on human factors in computing systems*, pages 1021–1032, 2016.
- [MRDR19] Alberto Monge Roffarello and Luigi De Russis. The race towards digital wellbeing: Issues and opportunities. In *Proceedings of the 2019 CHI conference on human factors in computing systems*, pages 1–14, 2019.
- [MRDR23] Alberto Monge Roffarello and Luigi De Russis. Achieving digital wellbeing through digital self-control tools: A systematic review and meta-analysis. *ACM Transactions on Computer-Human Interaction*, 30(4):1–66, 2023.
- [MRJ<sup>+</sup>13] Susan Michie, Michelle Richardson, Marie Johnston, Charles Abraham, Jill Francis, Wendy Hardeman, Martin P Eccles, James Cane, and Caroline E Wood. The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: building an international consensus for the reporting of behavior change interventions. *Annals of behavioral medicine*, 46(1):81–95, 2013.
- [MS99] Katherine McComas and James Shanahan. Telling stories about global climate change: Measuring the impact of narratives on issue cycles. *Communication research*, 26(1):30–57, 1999.

- [MS11a] Randy J McCarthy and John J Skowronski. You're getting warmer: Level of construal affects the impact of central traits on impression formation. *Journal of Experimental Social Psychology*, 47(6):1304–1307, 2011.
- [MS11b] Huang Hsiu Mei and Liaw Shu Sheng. Applying situated learning in a virtual reality system to enhance learning motivation. *International journal of information and education technology*, 1(4):298–302, 2011.
- [MS18] Linda Miksch and Charlotte Schulz. Disconnect to reconnect: The phenomenon of digital detox as a reaction to technology overload. 2018.
- [MSKRJ17] Arsalan Mosenia, Susmita Sur-Kolay, Anand Raghunathan, and Niraj K Jha. Wearable medical sensor-based system design: A survey. *IEEE Transactions on Multi-Scale Computing Systems*, 3(2):124–138, 2017.
- [MVS16] Robert Münscher, Max Vetter, and Thomas Scheuerle. A review and taxonomy of choice architecture techniques. *Journal of Behavioral Decision Making*, 29(5):511–524, 2016.
- [MVSW11] Susan Michie, Maartje M Van Stralen, and Robert West. The behaviour change wheel: a new method for characterising and designing behaviour change interventions. *Implementation science*, 6:1–12, 2011.
- [NAoSM<sup>+</sup>17] Engineering National Academies of Sciences, Medicine, et al. Communicating science effectively: A research agenda. 2017.
- [NBC<sup>+</sup>20] Nikita A Nekliudov, Oleg Blyuss, Ka Yan Cheung, Loukia Petrou, Jon Genuneit, Nikita Sushentsev, Anna Levadnaya, Pasquale Comberiati, John O Warner, Gareth Tudor-Williams, et al. Excessive media consumption about covid-19 is associated with increased state anxiety: outcomes of a large online survey in russia. *Journal of medical Internet research*, 22(9):e20955, 2020.
- [NCB18] Svetlana Nikitina, Sara Callaioli, and Marcos Baez. Smart conversational agents for reminiscence. In *Proceedings of the 1st international workshop on software engineering for cognitive services*, pages 52–57, 2018.
- [NDP18] Jasmin Niess, Sarah Diefenbach, and Axel Platz. Moving beyond assistance: psychological qualities of digital companions. In *Proceedings of the 10th Nordic Conference on Human-Computer Interaction*, pages 916–921, 2018.
- [NGS<sup>+</sup>05] Stephen P Norris, Sandra M Guilbert, Martha L Smith, Shahram Hakimehlahi, and Linda M Phillips. A theoretical framework for narrative explanation in science. *Science education*, 89(4):535–563, 2005.
- [NI12] Mamoun Nawahdah and Tomoo Inoue. Motion adaptive orientation adjustment of a virtual teacher to support physical task learning. *Information and Media Technologies*, 7(1):506–515, 2012.

- [NNP<sup>+</sup>21] Nikos Ntoumanis, Johan YY Ng, Andrew Prestwich, Eleanor Qusted, Jennie E Hancox, Cecilie Thøgersen-Ntoumani, Edward L Deci, Richard M Ryan, Chris Lonsdale, and Geoffrey C Williams. A meta-analysis of self-determination theory-informed intervention studies in the health domain: Effects on motivation, health behavior, physical, and psychological health. *Health psychology review*, 15(2):214–244, 2021.
- [NO16] Arinobu Niijima and Takefumi Ogawa. A proposal of virtual food texture by electric muscle stimulation. In *2016 IEEE International Conference on Multimedia & Expo Workshops (ICMEW)*, pages 1–6. IEEE, 2016.
- [Nor11] Kari Marie Norgaard. *Living in denial: Climate change, emotions, and everyday life*. mit Press, 2011.
- [Nor14] Don Norman. *Things that make us smart: Defending human attributes in the age of the machine*. Diversion Books, 2014.
- [NORV<sup>+</sup>] Juan Carlos Nieves, Mauricio Osorio, David Rojas-Velazquez, Yazmín Magallanes, and Andreas Brännström. Digital companions for well-being: Challenges and opportunities. *Journal of Intelligent & Fuzzy Systems*, (Preprint):1–11.
- [NOS<sup>+</sup>15] E Michael Nussbaum, Marissa C Owens, Gale M Sinatra, Abeera P Rehmat, Jacqueline R Cordova, Sajjad Ahmad, Fred C Harris Jr, and Sergiu M Dascalu. Losing the lake: Simulations to promote gains in student knowledge and interest about climate change. *International Journal of Environmental and Science Education*, 10(6):789–811, 2015.
- [NSJ20] André Natal, Glen Shires, and Philip Jägenstedt. Web Speech API. Draft Community Group Report, W3C Community Group, August 2020. <https://wicg.github.io/speech-api/> [Accessed: 10 March 2024].
- [NST94] Clifford Nass, Jonathan Steuer, and Ellen R Tauber. Computers are social actors. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 72–78, 1994.
- [NTL<sup>+</sup>21] Romain Nith, Shan-Yuan Teng, Pengyu Li, Yujie Tao, and Pedro Lopes. Dextremis: Increasing dexterity in electrical muscle stimulation by combining it with brakes. In *The 34th Annual ACM Symposium on User Interface Software and Technology*, pages 414–430, 2021.
- [NVPK23] Lise-Marie Nassen, Heidi Vandebosch, Karolien Poels, and Kathrin Karsay. Opt-out, abstain, unplug. a systematic review of the voluntary digital disconnection literature. *Telematics and Informatics*, page 101980, 2023.
- [NW20] Jasmin Niess and Paweł W Woźniak. Embracing companion technologies. In *Proceedings of the 11th Nordic Conference on Human-Computer Interaction: Shaping Experiences, Shaping Society*, pages 1–11, 2020.

- [NWQ06] David T Neal, Wendy Wood, and Jeffrey M Quinn. Habits—a repeat performance. *Current directions in psychological science*, 15(4):198–202, 2006.
- [Nyi21] Linus Nyiwul. Climate change adaptation and inequality in africa: Case of water, energy and food insecurity. *Journal of Cleaner Production*, 278:123393, 2021.
- [OAA<sup>+</sup>24] OpenAI:, Josh Achiam, Steven Adler, Sandhini Agarwal, Lama Ahmad, Ilge Akkaya, Florencia Leoni Aleman, Diogo Almeida, Janko Altschmidt, Sam Altman, Shyamal Anadkat, Red Avila, Igor Babuschkin, Suchir Balaji, Valerie Balcom, Paul Baltescu, Haiming Bao, Mohammad Bavarian, Jeff Belgum, Irwan Bello, Jake Berdine, Gabriel Bernadett-Shapiro, Christopher Berner, Lenny Bogdonoff, Oleg Boiko, Madelaine Boyd, Anna-Luisa Brakman, Greg Brockman, Tim Brooks, Miles Brundage, Kevin Button, Trevor Cai, Rosie Campbell, Andrew Cann, Brittany Carey, Chelsea Carlson, Rory Carmichael, Brooke Chan, Che Chang, Fotis Chantzis, Derek Chen, Sully Chen, Ruby Chen, Jason Chen, Mark Chen, Ben Chess, Chester Cho, Casey Chu, Hyung Won Chung, Dave Cummings, Jeremiah Currier, Yunxing Dai, Cory Decareaux, Thomas Degry, Noah Deutsch, Damien Deville, Arka Dhar, David Dohan, Steve Dowling, Sheila Dunning, Adrien Ecoffet, Atty Eleti, Tyna Eloundou, David Farhi, Liam Fedus, Niko Felix, Simón Posada Fishman, Juston Forte, Isabella Fulford, Leo Gao, Elie Georges, Christian Gibson, Vik Goel, Tarun Gogineni, Gabriel Goh, Rapha Gontijo-Lopes, Jonathan Gordon, Morgan Grafstein, Scott Gray, Ryan Greene, Joshua Gross, Shixiang Shane Gu, Yufei Guo, Chris Hallacy, Jesse Han, Jeff Harris, Yuchen He, Mike Heaton, Johannes Heidecke, Chris Hesse, Alan Hickey, Wade Hickey, Peter Hoeschele, Brandon Houghton, Kenny Hsu, Shengli Hu, Xin Hu, Joost Huizinga, Shantanu Jain, Shawn Jain, Joanne Jang, Angela Jiang, Roger Jiang, Haozhun Jin, Denny Jin, Shino Jomoto, Billie Jonn, Heewoo Jun, Tomer Kaftan, Łukasz Kaiser, Ali Kamali, Ingmar Kanitscheider, Nitish Shirish Keskar, Tabarak Khan, Logan Kilpatrick, Jong Wook Kim, Christina Kim, Yongjik Kim, Jan Hendrik Kirchner, Jamie Kiros, Matt Knight, Daniel Kokotajlo, Łukasz Kondraciuk, Andrew Kondrich, Aris Konstantinidis, Kyle Kosic, Gretchen Krueger, Vishal Kuo, Michael Lampe, Ikai Lan, Teddy Lee, Jan Leike, Jade Leung, Daniel Levy, Chak Ming Li, Rachel Lim, Molly Lin, Stephanie Lin, Mateusz Litwin, Theresa Lopez, Ryan Lowe, Patricia Lue, Anna Makanju, Kim Malfacini, Sam Manning, Todor Markov, Yaniv Markovski, Bianca Martin, Katie Mayer, Andrew Mayne, Bob McGrew, Scott Mayer McKinney, Christine McLeavey, Paul McMillan, Jake McNeil, David Medina, Aalok Mehta, Jacob Menick, Luke Metz, Andrey Mishchenko, Pamela Mishkin, Vinnie Monaco, Evan Morikawa, Daniel Mossing, Tong Mu, Mira Murati, Oleg Murk, David Mély, Ashvin Nair, Reiichiro Nakano, Rajeev

Nayak, Arvind Neelakantan, Richard Ngo, Hyeonwoo Noh, Long Ouyang, Cullen O’Keefe, Jakub Pachocki, Alex Paino, Joe Palermo, Ashley Pantuliano, Giambattista Parascandolo, Joel Parish, Emy Parparita, Alex Passos, Mikhail Pavlov, Andrew Peng, Adam Perelman, Filipe de Avila Belbute Peres, Michael Petrov, Henrique Ponde de Oliveira Pinto, Michael, Pokorny, Michelle Pokrass, Vitchyr H. Pong, Tolly Powell, Alethea Power, Boris Power, Elizabeth Proehl, Raul Puri, Alec Radford, Jack Rae, Aditya Ramesh, Cameron Raymond, Francis Real, Kendra Rimbach, Carl Ross, Bob Rotsted, Henri Roussez, Nick Ryder, Mario Saltarelli, Ted Sanders, Shibani Santurkar, Girish Sastry, Heather Schmidt, David Schnurr, John Schulman, Daniel Selsam, Kyla Sheppard, Toki Sherbakov, Jessica Shieh, Sarah Shoker, Pranav Shyam, Szymon Sidor, Eric Sigler, Maddie Simens, Jordan Sitkin, Katarina Slama, Ian Sohl, Benjamin Sokolowsky, Yang Song, Natalie Staudacher, Felipe Petroski Such, Natalie Summers, Ilya Sutskever, Jie Tang, Nikolas Tezak, Madeleine B. Thompson, Phil Tillet, Amin Tootoonchian, Elizabeth Tseng, Preston Tuggle, Nick Turley, Jerry Tworek, Juan Felipe Cerón Uribe, Andrea Vallone, Arun Vijayvergiya, Chelsea Voss, Carroll Wainwright, Justin Jay Wang, Alvin Wang, Ben Wang, Jonathan Ward, Jason Wei, CJ Weinmann, Akila Welihinda, Peter Welinder, Jiayi Weng, Lilian Weng, Matt Wiethoff, Dave Willner, Clemens Winter, Samuel Wolrich, Hannah Wong, Lauren Workman, Sherwin Wu, Jeff Wu, Michael Wu, Kai Xiao, Tao Xu, Sarah Yoo, Kevin Yu, Qiming Yuan, Wojciech Zaremba, Rowan Zellers, Chong Zhang, Marvin Zhang, Shengjia Zhao, Tianhao Zheng, Juntang Zhuang, William Zhuk, and Barret Zoph. GPT-4 Technical Report, 2024.

- [ODH<sup>+</sup>22] Charles A Ogunbode, Rouven Doran, Daniel Hanss, Maria Ojala, Katariina Salmela-Aro, Karlijn L van den Broek, Navjot Bhullar, Sibebe D Aquino, Tiago Marot, Julie Aitken Schermer, et al. Climate anxiety, wellbeing and pro-environmental action: correlates of negative emotional responses to climate change in 32 countries. *Journal of Environmental Psychology*, 84:101887, 2022.
- [OGPOL18] Tania Ouariachi, José Gutiérrez-Pérez, and María-Dolores Olvera-Lobo. Can serious games help to mitigate climate change? exploring their influence on spanish and american teenagers’ attitudes/*¿ pueden los serious games ayudar a mitigar el cambio climático? una exploración de su influencia sobre las actitudes de los adolescentes españoles y estadounidenses. *Psycology*, 9(3):365–395, 2018.*
- [OH21] Regina Obe and Leo S Hsu. *PostGIS in action*. Simon and Schuster, 2021.
- [Oja12] Maria Ojala. Hope and climate change: The importance of hope for environmental engagement among young people. *Environmental education research*, 18(5):625–642, 2012.

- [Oka09] Allison M. Okamura. Haptic Feedback in Robot-Assisted Minimally Invasive Surgery. *Current opinion in urology*, 19(1):102–107, January 2009.
- [OOLGP17] Tania Ouariachi, María Dolores Olvera-Lobo, and José Gutiérrez-Pérez. Analyzing climate change communication through online games: Development and application of validated criteria. *Science communication*, 39(1):10–44, 2017.
- [Ope09] OpenGameArt.org. OpenGameArt.org, 2009.
- [ORC<sup>+</sup>13] Karen O’Brien, Jonathan Reams, Anne Caspari, Andrew Dugmore, Maryam Faghihimani, Ioan Fazey, Heide Hackmann, David Manuel-Navarrete, John Marks, Riel Miller, et al. You say you want a revolution? transforming education and capacity building in response to global change. *Environmental Science & Policy*, 28:48–59, 2013.
- [ORMR12] Antti Oulasvirta, Tye Rattenbury, Lingyi Ma, and Eeva Raita. Habits make smartphone use more pervasive. *Personal and Ubiquitous computing*, 16:105–114, 2012.
- [OSDE18a] Fabian Okeke, Michael Sobolev, Nicola Dell, and Deborah Estrin. Good vibrations: Can a digital nudge reduce digital overload? In *Proceedings of the 20th International Conference on Human-Computer Interaction with Mobile Devices and Services*, MobileHCI ’18, New York, NY, USA, 2018. Association for Computing Machinery.
- [OSDE18b] Fabian Okeke, Michael Sobolev, Nicola Dell, and Deborah Estrin. Good vibrations: can a digital nudge reduce digital overload? In *Proceedings of the 20th international conference on human-computer interaction with mobile devices and services*, pages 1–12, 2018.
- [OZ10] Salyani Osman and Nor Azan Haji Mat Zin. Proposed model for courseware development of virtual teaching and learning traditional craft. In *2010 International Symposium on Information Technology*, volume 1, pages 1–6. IEEE, 2010.
- [OZM<sup>+</sup>20] Samwel Opiyo, Jun Zhou, Emmy Mwangi, Wang Kai, and Idris Sunusi. A review on teleoperation of mobile ground robots: Architecture and situation awareness. *International Journal of Control, Automation and Systems*, 19(3):1384–1407, October 2020.
- [PAKdS08] Christopher Peters, Stylianos Asteriadis, Kostas Karpouzis, and Etienne de Sevin. Towards a real-time gaze-based shared attention for a virtual agent. In *International Conference on Multimodal Interfaces*, 2008.

- [PB09] Alexandros Pantelopoulos and Nikolaos G Bourbakis. A survey on wearable sensor-based systems for health monitoring and prognosis. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)*, 40(1):1–12, 2009.
- [PBH20a] Aditya Kumar Purohit, Louis Barclay, and Adrian Holzer. Designing for digital detox: Making social media less addictive with digital nudges. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*, pages 1–9, 2020.
- [PBH20b] Aditya Kumar Purohit, Louis Barclay, and Adrian Holzer. Designing for digital detox: Making social media less addictive with digital nudges. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*, pages 1–9, 2020.
- [PBML16] Stefania Pizza, Barry Brown, Donald McMillan, and Airi Lampinen. Smartwatch in vivo. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, pages 5456–5469, 2016.
- [PBS<sup>+</sup>23] Aditya Kumar Purohit, Torben Jan Barev, Sofia Schöbel, Andreas Janson, and Adrian Holzer. Designing for digitalwellbeing on a smartphone: Co-creation of digital nudges to mitigate instagram overuse. 2023.
- [PC18] Tayana Panova and Xavier Carbonell. Is smartphone addiction really an addiction? *Journal of behavioral addictions*, 7(2):252–259, 2018.
- [PCM23] Veruschka Pelser-Carstens and Gordon Matthew. Workshop 2: The art of serious game design for educational use: A workshop presentation for novice lecturers. In *EdMedia+ Innovate Learning*, pages 817–824. Association for the Advancement of Computing in Education (AACE), 2023.
- [PCR18] Dorian Peters, Rafael A Calvo, and Richard M Ryan. Designing for motivation, engagement and wellbeing in digital experience. *Frontiers in psychology*, page 797, 2018.
- [PCY<sup>+</sup>06] Zhigeng Pan, Adrian David Cheok, Hongwei Yang, Jiejie Zhu, and Jiaoying Shi. Virtual reality and mixed reality for virtual learning environments. *Computers & graphics*, 30(1):20–28, 2006.
- [PDR16] Max Pfeiffer, Tim Duentel, and Michael Rohs. Let your body move: a prototyping toolkit for wearable force feedback with electrical muscle stimulation. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services*, pages 418–427, 2016.

- [PDS<sup>+</sup>15] Max Pfeiffer, Tim Dünthe, Stefan Schneegass, Florian Alt, and Michael Rohs. Cruise control for pedestrians: Controlling walking direction using electrical muscle stimulation. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, pages 2505–2514, 2015.
- [Pel16] Pelias Contributors. Pelias Geocoder, 2016. <https://www.pelias.io/> [Accessed: 15 January 2024].
- [PF13] Ronald Petrick and Mary Ellen Foster. Planning for social interaction in a robot bartender domain. In *Proceedings of the International Conference on Automated Planning and Scheduling*, volume 23, pages 389–397, 2013.
- [PFL19] Alisha Pradhan, Leah Findlater, and Amanda Lazar. "phantom friend" or "just a box with information" personification and ontological categorization of smart speaker-based voice assistants by older adults. *Proceedings of the ACM on human-computer interaction*, 3(CSCW):1–21, 2019.
- [PH91] Seymour Papert and Idit Harel. Situating constructionism. *constructionism*, 36(2):1–11, 1991.
- [PH21] Aditya Kumar Purohit and Adrian Holzer. Unhooked by design: Scrolling mindfully on social media by automating digital nudges. In *AMCIS*, volume 21, pages 1–10, 2021.
- [PHK18] Henning Pohl, Kasper Hornbæk, and Jarrod Knibbe. Wandering through space: Interactive calibration for electric muscle stimulation. In *Proceedings of the 9th Augmented Human International Conference*, pages 1–5, 2018.
- [PHWH14] Christian Peters, Thomas Hermann, Sven Wachsmuth, and Jesse Hoey. Automatic task assistance for people with cognitive disabilities in brushing teeth—a user study with the tebra system. *ACM Transactions on Accessible Computing (TACCESS)*, 5(4):1–34, 2014.
- [Pic00] Rosalind W Picard. *Affective computing*. MIT press, 2000.
- [PK12] Timo Partala and Aleksi Kallinen. Understanding the most satisfying and unsatisfying user experiences: Emotions, psychological needs, and context. *Interacting with computers*, 24(1):25–34, 2012.
- [PIRM<sup>+</sup>23] Douglas A Parry, Daniel B le Roux, Joshua Morton, Ruth Pons, Ruan Pretorius, and Andre Schoeman. Digital wellbeing applications: Adoption, use and perceived effects. *Computers in Human Behavior*, 139:107542, 2023.
- [PLS<sup>+</sup>21] Christian Plotzky, Ulrike Lindwedel, Michaela Sorber, Barbara Loessl, Peter König, Christophe Kunze, Christiane Kugler, and Michael Meng.

- Virtual reality simulations in nurse education: A systematic mapping review. *Nurse education today*, 101:104868, 2021.
- [PM08] Dorin Mircea Popovici and Ana-Maria Marhan. Virtual reality-based environments for learning and training. *Product engineering: Tools and methods based on virtual reality*, pages 123–142, 2008.
- [PMP<sup>+</sup>03] Joelle Pineau, Michael Montemerlo, Martha Pollack, Nicholas Roy, and Sebastian Thrun. Towards robotic assistants in nursing homes: Challenges and results. *Robotics and autonomous systems*, 42(3-4):271–281, 2003.
- [PNV<sup>+</sup>20] P Marijn Poortvliet, Meredith T Niles, Jeroen A Veraart, Saskia E Werners, Fiona C Korporaal, and Bob C Mulder. Communicating climate change risk: A content analysis of ipcc’s summary for policymakers. *Sustainability*, 12(12):4861, 2020.
- [Poh93] Reinhard Pohl. The widening of ems bands: A necessary but temporary measure. *Economic Bulletin*, 30(9):1–7, 1993.
- [pol21] poly.pizza. Poly Pizza, 2021.
- [PR17] Martin Pielot and Luz Rello. Productive, anxious, lonely: 24 hours without push notifications. In *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services, MobileHCI ’17*, New York, NY, USA, 2017. Association for Computing Machinery.
- [Pre01] Marc Prensky. Digital natives, digital immigrants part 2: Do they really think differently? *On the horizon*, 9(6):1–6, 2001.
- [PS08] Luc G Pelletier and Elizabeth Sharp. Persuasive communication and pro-environmental behaviours: How message tailoring and message framing can improve the integration of behaviours through self-determined motivation. *Canadian Psychology/Psychologie Canadienne*, 49(3):210, 2008.
- [PSA13] Max Pfeiffer, Stefan Schneegaß, and Florian Alt. Supporting interaction in public space with electrical muscle stimulation. In *Proceedings of the 2013 ACM conference on Pervasive and ubiquitous computing adjunct publication*, pages 5–8, 2013.
- [PSK<sup>+</sup>20] Michael Panzirsch, Harsimran Singh, Thomas Krüger, Christian Ott, and Alin Albu-Schäffer. Safe Interactions and Kinesthetic Feedback in High Performance Earth-To-Moon Teleoperation. In *2020 IEEE Aerospace Conference*, pages 1–10, March 2020.
- [PVCB18] Charlie Pinder, Jo Vermeulen, Benjamin R Cowan, and Russell Beale. Digital behaviour change interventions to break and form habits. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 25(3):1–66, 2018.

- [PVP18] Jérôme Perret and Emmanuel Vander Poorten. Touching virtual reality: a review of haptic gloves. In *ACTUATOR 2018; 16th International Conference on New Actuators*, pages 1–5. VDE, 2018.
- [PW13] Daniel S. Pamungkas and Koren Ward. Tele-operation of a robot arm with electro tactile feedback. In *2013 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, pages 704–709, 2013.
- [QJSP21] Jessie M Quintero Johnson, Angeline Sangalang, and Sun-Young Park. First-person, third-person, or bystander? exploring the persuasive influence of perspective in mental health narratives. *Journal of Health Communication*, 26(4):225–238, 2021.
- [QRD<sup>+</sup>18] Chris Quintana, Brian J Reiser, Elizabeth A Davis, Joseph Krajcik, Eric Fretz, Ravit Golan Duncan, Eleni Kyza, Daniel Edelson, and Elliot Soloway. A scaffolding design framework for software to support science inquiry. In *The journal of the learning sciences*, pages 337–386. Psychology Press, 2018.
- [RAS<sup>+</sup>21] Theda Radtke, Theresa Apel, Konstantin Schenkel, Jan Keller, and Eike von Lindern. Digital detox: An effective solution in the smartphone era? a systematic literature review. *Mobile Media & Communication*, page 20501579211028647, 2021.
- [RAS<sup>+</sup>22] Theda Radtke, Theresa Apel, Konstantin Schenkel, Jan Keller, and Eike von Lindern. Digital detox: An effective solution in the smartphone era? a systematic literature review. *Mobile Media & Communication*, 10(2):190–215, 2022.
- [RB02] Mihail C Roco and William Sims Bainbridge. Converging technologies for improving human performance: Integrating from the nanoscale. *Journal of nanoparticle research*, 4:281–295, 2002.
- [RD00] Richard M Ryan and Edward L Deci. Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American psychologist*, 55(1):68, 2000.
- [RD17] Richard M Ryan and Edward L Deci. *Self-determination theory: Basic psychological needs in motivation, development, and wellness*. Guilford publications, 2017.
- [RDDD<sup>+</sup>22] Richard M Ryan, Jasper J Duineveld, Stefano I Di Domenico, William S Ryan, Ben A Steward, and Emma L Bradshaw. We know this much is (meta-analytically) true: A meta-review of meta-analytic findings evaluating self-determination theory. *Psychological Bulletin*, 148(11-12):813, 2022.

- [RDN<sup>+</sup>02] Vincent Rialle, Florence Duchene, Norbert Noury, Lionel Bajolle, and Jacques Demongeot. Health" smart" home: information technology for patients at home. *Telemedicine Journal and E-Health*, 8(4):395–409, 2002.
- [RE] Diana Reckien and Klaus Eisenack. Climate change gaming on board and screen: A review. 44(2):253–271.
- [RE13] Diana Reckien and Klaus Eisenack. Climate change gaming on board and screen: A review. *Simulation & Gaming*, 44(2-3):253–271, 2013.
- [Red11] Red Redemption. Fate of the world, 2011. Game [PC].
- [RFB20] Alexandra Rowland, Erwin Folmer, and Wouter Beek. Towards Self-Service GIS—Combining the Best of the Semantic Web and Web GIS. *ISPRS International Journal of Geo-Information*, 9:753, 12 2020.
- [RHK17] Petra Rust, Verena Hasenegger, and Jürgen König. *Österreichischer Ernährungsbericht 2017*. Department für Ernährungswissenschaften der Universität Wien, 2017.
- [RIP99] Alexander Repenning, Andri Ioannidou, and Jonathan Phillips. Collaborative use & design of interactive simulations. 1999.
- [RJAF17] Andreas Riener, Myoungsoon Jeon, Ignacio Alvarez, and Anna K Frison. Driver in the loop: Best practices in automotive sensing and feedback mechanisms. In *Automotive user interfaces*, pages 295–323. Springer, 2017.
- [RMFW20] Jaziar Radianti, Tim A. Majchrzak, Jennifer Fromm, and Isabell Wohlgenannt. A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers Education*, 147:103778, 2020.
- [RMN21] Sathiya Kumar Renganayagalu, Steven C Mallam, and Salman Nazir. Effectiveness of vr head mounted displays in professional training: A systematic review. *Technology, Knowledge and Learning*, pages 1–43, 2021.
- [RPP14] Reza Rawassizadeh, Blaine A Price, and Marian Petre. Wearables: Has the age of smartwatches finally arrived? *Communications of the ACM*, 58(1):45–47, 2014.
- [RS22] Daniel J. Rea and Stela H. Seo. Still not solved: A call for renewed focus on user-centered teleoperation interfaces. *Frontiers in Robotics and AI*, 9, March 2022.
- [RSF<sup>+</sup>03] Ingmar Rauschert, Rajeev Sharma, Sven Fuhrmann, Isaac Brewer, and Alan MacEachren. Approaching a New Multimodal GIS-Interface. 03 2003.

- [S<sup>+</sup>65] Ivan E Sutherland et al. The ultimate display. In *Proceedings of the IFIP Congress*, volume 2, pages 506–508. New York, 1965.
- [SAS21] R Shabahang, MS Aruguete, and H Shim. Online news addiction: future anxiety, fear of missing out on news, and interpersonal trust contribute to excessive online news consumption. *Online Journal of Communication and Media Technologies*, 11(2):e202105, 2021.
- [SAVL<sup>+</sup>16] Stephanie Schoeppe, Stephanie Alley, Wendy Van Lippevelde, Nicola A Bray, Susan L Williams, Mitch J Duncan, and Corneel Vandelanotte. Efficacy of interventions that use apps to improve diet, physical activity and sedentary behaviour: a systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, 13:1–26, 2016.
- [Say20] Sergio Sayago. Voice assistants as learning companions: An initial exploration with computer science students. In *22nd International Conference on Human-Computer Interaction with Mobile Devices and Services*, pages 1–3, 2020.
- [SB64] Paul F Secord and Carl W Backman. Interpersonal congruency, perceived similarity, and friendship. *Sociometry*, pages 115–127, 1964.
- [SB18] Angeline Sangalang and Emma Frances Bloomfield. Mother goose and mother nature: designing stories to communicate information about climate change. *Communication Studies*, 69(5):583–604, 2018.
- [SC03] William R Sherman and Alan B Craig. Understanding virtual reality. *San Francisco, CA: Morgan Kaufman*, 2003.
- [Sch12] Mike S Schäfer. Online communication on climate change and climate politics: a literature review. *Wiley Interdisciplinary Reviews: Climate Change*, 3(6):527–543, 2012.
- [Sch19] RX Schwartz. Ulysses’ ropes and the inherent limits of digital self-control tools. 2019.
- [SCT<sup>+</sup>19] Thomas Svensson, Ung-il Chung, Shinichi Tokuno, Mitsuteru Nakamura, and Akiko Kishi Svensson. A validation study of a consumer wearable sleep tracker compared to a portable eeg system in naturalistic conditions. *Journal of Psychosomatic Research*, 126:109822, 2019.
- [SDG17] Anna Syberfeldt, Oscar Danielsson, and Patrik Gustavsson. Augmented reality smart glasses in the smart factory: Product evaluation guidelines and review of available products. *Ieee Access*, 5:9118–9130, 2017.

- [SEKK01] Kennon M Sheldon, Andrew J Elliot, Youngmee Kim, and Tim Kasser. What is satisfying about satisfying events? testing 10 candidate psychological needs. *Journal of personality and social psychology*, 80(2):325, 2001.
- [SFLRS18] Helmut Schrom-Feiertag, Florian Lorenz, Georg Regal, and Volker Settgast. Augmented and virtual reality applied for innovative, inclusive and efficient participatory planning. In *Proceedings of 7th Transport Research Arena TRA 2018*. 2018.
- [SFSS17] Helmut Schrom-Feiertag, Volker Settgast, and Stefan Seer. Evaluation of indoor guidance systems using eye tracking in an immersive virtual environment. *Spatial Cognition & Computation*, 17(1-2):163–183, 2017.
- [SGM07] Caifeng Shan, Shaogang Gong, and Peter W McOwan. Beyond facial expressions: Learning human emotion from body gestures. In *BMVC*, pages 1–10, 2007.
- [SGM21] Janick Spirig, Kimberly Garcia, and Simon Mayer. An expert digital companion for working environments. In *Proceedings of the 11th International Conference on the Internet of Things*, pages 25–32, 2021.
- [SGMS17] Freeha Sharif, Samina Ghulam, Arshad Nawaz Malik, and Quratulain Saeed. Effectiveness of functional electrical stimulation (fes) versus conventional electrical stimulation in gait rehabilitation of patients with stroke. *J Coll Physicians Surg Pak*, 27(11):703–706, 2017.
- [SH16] Maya Samaha and Nazir S Hawi. Relationships among smartphone addiction, stress, academic performance, and satisfaction with life. *Computers in human behavior*, 57:321–325, 2016.
- [SHT17a] Martin Schrepp, Andreas Hinderks, and Jörg Thomaschewski. Design and Evaluation of a Short Version of the User Experience Questionnaire (UEQ-S). *International Journal of Interactive Multimedia and Artificial Intelligence*, 4, 2017.
- [SHT17b] Martin Schrepp, Andreas Hinderks, and Jörg Thomaschewski. Design and evaluation of a short version of the user experience questionnaire (ueq-s). *International Journal of Interactive Multimedia and Artificial Intelligence*, 4:103, 01 2017.
- [SKHH19] Valentin Schwind, Pascal Knierim, Nico Haas, and Niels Henze. Using presence questionnaires in virtual reality. In *Proceedings of the 2019 CHI conference on human factors in computing systems*, pages 1–12, 2019.
- [SKR<sup>+</sup>21] Sei Yon Sohn, Lauren Krasnoff, Philippa Rees, Nicola J Kalk, and Ben Carter. The association between smartphone addiction and sleep: a uk

- cross-sectional study of young adults. *Frontiers in psychiatry*, 12:629407, 2021.
- [SKV19] Marios Stanitsas, Konstantinos Kirytopoulos, and Elise Vareilles. Facilitating sustainability transition through serious games: A systematic literature review. *Journal of cleaner production*, 208:924–936, 2019.
- [SL16] Jeff Sauro and James R Lewis. *Quantifying the user experience: Practical statistics for user research*. Morgan Kaufmann, 2016.
- [SLEL<sup>+</sup>20] Camille Sagnier, Emilie Loup-Escande, Domitile Lourdeaux, Indira Thouvenin, and Gérard Valléry. User acceptance of virtual reality: an extended technology acceptance model. *International Journal of Human–Computer Interaction*, 36(11):993–1007, 2020.
- [SMRDRA21] RX Schwartz, Alberto Monge Roffarello, Luigi De Russis, and Panagiotis Apostolellis. Reducing risk in digital self-control tools: design patterns and prototype. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*, pages 1–7, 2021.
- [SMWM22] Ambika Shahu, Alexander Melem, Philipp Wintersberger, and Florian Michahelles. Nudgit-reducing online news consumption by digital nudges. In *Adjunct Publication of the 24th International Conference on Human-Computer Interaction with Mobile Devices and Services*, pages 1–5, 2022.
- [SMY15] Cary Stothart, Ainsley Mitchum, and Courtney Yehmert. The attentional cost of receiving a cell phone notification. *Journal of experimental psychology: human perception and performance*, 41(4):893, 2015.
- [SNW17] RB Stevenson, J Nicholls, and H Whitehouse. What is climate change education? curric perspect, 2017.
- [SO01] Stephen R Sterling and David Orr. *Sustainable education: Re-visioning learning and change*, volume 6. Green Books for the Schumacher Society Totnes, 2001.
- [SP13] Akane Sano and Rosalind W Picard. Stress recognition using wearable sensors and mobile phones. In *2013 Humaine association conference on affective computing and intelligent interaction*, pages 671–676. IEEE, 2013.
- [SPA<sup>+</sup>15] Akane Sano, Andrew J Phillips, Z Yu Amy, Andrew W McHill, Sara Taylor, Natasha Jaques, Charles A Czeisler, Elizabeth B Klerman, and Rosalind W Picard. Recognizing academic performance, sleep quality, stress level, and mental health using personality traits, wearable sensors and mobile phones. In *2015 IEEE 12th international conference on wearable and implantable body sensor networks (BSN)*, pages 1–6. IEEE, 2015.

- [SPD21] Robert Soden, Pradnaya Pathak, and Olivia Doggett. What we speculate about when we speculate about sustainable hci. In *ACM SIGCAS Conference on Computing and Sustainable Societies*, pages 188–198, 2021.
- [SQP<sup>+</sup>14] Thomas Stocker, Dahe Qin, Gian-Kasper Plattner, Melinda Tignor, Simon Allen, Judith Boschung, Alexander Nauels, Yu Xia, Vincent Bex, and Pauline Midgley. Summary for policymakers. 2014.
- [SR16] Stefan Schneegass and Rufat Rzayev. Embodied notifications: Implicit notifications through electrical muscle stimulation. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct*, pages 954–959, 2016.
- [SRKS20] Stephanie Schwarz, Georg Regal, Marina Kempf, and Raimund Schatz. Learning success in immersive virtual reality training environments: practical evidence from automotive assembly. In *Proceedings of the 11th nordic conference on human-computer interaction: shaping experiences, shaping society*, pages 1–11, 2020.
- [SRP<sup>+</sup>18] Cameron Steer, Simon Robinson, Jennifer Pearson, Deepak Sahoo, Ian Mabbett, and Matt Jones. A liquid tangible display for mobile colour mixing. In *proceedings of the 20th International Conference on Human-Computer Interaction with Mobile Devices and Services*, pages 1–7, 2018.
- [SS<sup>+</sup>18] Priyal P Shah, Megha S Sheth, et al. Correlation of smartphone use addiction with text neck syndrome and sms thumb in physiotherapy students. *Int J Community Med Public Health*, 5(6):2512, 2018.
- [SSFH18] Alex Sciuto, Arnita Saini, Jodi Forlizzi, and Jason I Hong. " hey alexa, what's up?" a mixed-methods studies of in-home conversational agent usage. In *Proceedings of the 2018 designing interactive systems conference*, pages 857–868, 2018.
- [Sta05] Gary Stager. Papertian constructionism and the design of productive contexts for learning. In *Proc. of EuroLogo*, pages 43–53. Citeseer, 2005.
- [Sta22] Stadt Wien. Wiener Abfallwirtschaft erzielt positive Bilanz bei Emissionen, 2022.
- [Sta23] Statistik Austria. Annual average population, 2023.
- [Ste93] BE Stein. *The Merging of the Senses*. MIT Press, 1993.
- [Ste00] Paul C Stern. New environmental theories: toward a coherent theory of environmentally significant behavior. *Journal of social issues*, 56(3):407–424, 2000.

- [Sto15] Per Espen Stoknes. *What we think about when we try not to think about global warming: Toward a new psychology of climate action*. Chelsea Green Publishing, 2015.
- [Sto17] PE Stoknes. What we try to think about when we try not to think about global warming, 2017.
- [Suc87] Lucille Alice Suchman. *Plans and situated actions: The problem of human-machine communication*. Cambridge university press, 1987.
- [SW05] Penelope Sweetser and Peta Wyeth. Gameflow: a model for evaluating player enjoyment in games. *Computers in Entertainment (CIE)*, 3(3):3–3, 2005.
- [SWH<sup>+</sup>12] Mikel Sagardia, Bernhard Weber, Thomas Hulin, Gerd Hirzinger, and Carsten Preusche. Evaluation of visual and force feedback in virtual assembly verifications. In *2012 IEEE Virtual Reality Workshops (VRW)*, pages 23–26, 2012.
- [SWM22a] Ambika Shahu, Philipp Wintersberger, and Florian Michahelles. Scenario-based investigation of acceptance of electric muscle stimulation. In *Augmented Humans 2022*, pages 184–194. 2022.
- [SWM22b] Ambika Shahu, Philipp Wintersberger, and Florian Michahelles. Would users accept electric muscle stimulation controlling their body? insights from a scenario-based investigation. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts*, pages 1–7, 2022.
- [Syv20] Trine Syvertsen. *Digital detox: The politics of disconnecting*. emerald publishing limited, 2020.
- [TAL18] YM Tang, KM Au, and Yohana Leung. Comprehending products with mixed reality: Geometric relationships and creativity. *International Journal of Engineering Business Management*, 10:1847979018809599, 2018.
- [TD92] PC Thomas and WM David. Augmented reality: An application of heads-up display technology to manual manufacturing processes. In *Hawaii international conference on system sciences*, volume 2. ACM SIGCHI Bulletin, 1992.
- [TFRR14] Bill Thornton, Alyson Faires, Maija Robbins, and Eric Rollins. The mere presence of a cell phone may be distracting. *Social Psychology*, 2014.
- [Tha18] Richard H Thaler. *Nudge, not sludge*, 2018.
- [THG<sup>+</sup>22] Nada Terzimehić, Luke Haliburton, Philipp Greiner, Albrecht Schmidt, Heinrich Hussmann, and Ville Mäkelä. Mindphone: Mindful reflection at unlock can reduce absentminded smartphone use. In *Designing Interactive Systems Conference*, pages 1818–1830, 2022.

- [Thi13] Julien Thiennot. Cookie Clicker, 2013. publisher: DashNet.
- [Tho18] Sara Thomée. Mobile phone use and mental health. a review of the research that takes a psychological perspective on exposure. *International journal of environmental research and public health*, 15(12):2692, 2018.
- [Tho20] Alan Thorn. Introducing Godot: Why Migrate? In Alan Thorn, editor, *Moving from Unity to Godot: An In-Depth Handbook to Godot for Unity Users*, pages 1–14. Apress, Berkeley, CA, 2020.
- [TLW07] Yaacov Trope, Nira Liberman, and Cheryl Wakslak. Construal levels and psychological distance: Effects on representation, prediction, evaluation, and behavior. *Journal of consumer psychology*, 17(2):83–95, 2007.
- [TMR11] Emi Tamaki, Takashi Miyaki, and Jun Rekimoto. Possessedhand: techniques for controlling human hands using electrical muscles stimuli. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 543–552, 2011.
- [TNLK22] Daisuke Tajima, Jun Nishida, Pedro Lopes, and Shunichi Kasahara. Whose touch is this?: Understanding the agency trade-off between user-driven touch vs. computer-driven touch. *ACM Transactions on Computer-Human Interaction*, 29(3):1–27, 2022.
- [TPB<sup>+</sup>17] Eduardo H Tanaka, Juliana A Paludo, Rafael Bacchetti, Edgar V Gadbem, Leonardo R Domingues, Carlúcio S Cordeiro, Olavo Giraldi, Guilherme Alcarde Gallo, Adam Mendes da Silva, and Marcos H Cascone. Immersive virtual training for substation electricians. In *2017 IEEE Virtual Reality (VR)*, pages 451–452. IEEE, 2017.
- [TPG<sup>+</sup>21] Eduardo H Tanaka, Tiago Z Paula, Guilherme SF Gouveia, Rovilson AF Leal Junior, Lucimara de Almeida, Leonardo R Domingues, Alex HF Alves, and Roberta R Oliveira. A virtual reality simulator for training electricians to work on electric power distribution network. *IADIS International Journal on WWW/Internet*, 19(2), 2021.
- [TS85] Tom Trabasso and Linda L Sperry. Causal relatedness and importance of story events. *Journal of Memory and language*, 24(5):595–611, 1985.
- [TS08] R Thaler and C Sunstein. Nudge: Improving decisions about health, wealth and happiness. In *Amsterdam Law Forum; HeinOnline: Online*, page 89. HeinOnline, 2008.
- [Udd19] Md Zia Uddin. A wearable sensor-based activity prediction system to facilitate edge computing in smart healthcare system. *Journal of Parallel and Distributed Computing*, 123:46–53, 2019.

- [Umw22a] Umweltbundesamt. Austria's National Inventory Report 2022. Technical Report 0811, Wien, 2022.
- [Umw22b] Umweltbundesamt. Emissionsfaktoren für Verkehrsmittel, 2022. publisher: Umweltbundesamt.
- [US 15] US EPA. Greenhouse Gases Equivalencies Calculator - Calculations and References, August 2015.
- [USD23] USDA. FoodData Central, 2023. publisher: U.S. Department of Agriculture.
- [VD00] Viswanath Venkatesh and Fred D Davis. A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management science*, 46(2):186–204, 2000.
- [VKS16] Peter Vorderer, Nicola Krömer, and Frank M Schneider. Permanently online–permanently connected: Explorations into university students' use of social media and mobile smart devices. *Computers in Human Behavior*, 63:694–703, 2016.
- [VMDD03] Viswanath Venkatesh, Michael G Morris, Gordon B Davis, and Fred D Davis. User acceptance of information technology: Toward a unified view. *MIS quarterly*, pages 425–478, 2003.
- [VMvB<sup>+</sup>] Joost M. Vervoort, Manjana Milkoreit, Lisette van Beek, Astrid C. Mangnus, David Farrell, Steven R. McGreevy, Kazuhiko Ota, Christoph D.D. Rupperecht, Jason B. Reed, and Matthew Huber. Not just playing: The politics of designing games for impact on anticipatory climate governance. 137:213–221.
- [VSVB<sup>+</sup>17] Aku Visuri, Zhanna Sarsenbayeva, Niels Van Berkel, Jorge Goncalves, Reza Rawassizadeh, Vassilis Kostakos, and Denzil Ferreira. Quantifying sources and types of smartwatch usage sessions. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, pages 3569–3581, 2017.
- [VVR18] Bas Verplanken, B Verplanken, and Ryan. *Psychology of habit*. Springer, 2018.
- [Wae90] Yvonne Waern. *Cognitive aspects of computer supported tasks*. John Wiley & Sons, Inc., 1990.
- [WAH<sup>+</sup>13] Jeroen G.W. Wildenbeest, David A. Abbink, Cock J.M. Heemskerk, Frans C.T. van der Helm, and Henri Boessenkool. The impact of haptic feedback quality on the performance of teleoperated assembly tasks. *IEEE Transactions on Haptics*, 6(2):242–252, 2013.

- [WCB<sup>+</sup>18] Minjuan Wang, Vic Callaghan, Jodi Bernhardt, Kevin White, and Anasol Peña-Rios. Augmented reality in education and training: pedagogical approaches and illustrative case studies. *Journal of ambient intelligence and humanized computing*, 9(5):1391–1402, 2018.
- [WGS<sup>+</sup>06] Dawn K Wilson, Sarah Griffin, Ruth P Saunders, Alexandra Evans, Gary Mixon, Marcie Wright, Amelia Beasley, M Renee Umstatted, Diana Lattimore, Ashley Watts, et al. Formative evaluation of a motivational intervention for increasing physical activity in underserved youth. *Evaluation and Program Planning*, 29(3):260–268, 2006.
- [WH23] Sebastian Weiß and Wilko Heuten. Don't panic!-influence of virtual stressor representations from the icu context on perceived stress levels. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, pages 1–15, 2023.
- [Wil11] Yorick Wilks. Close engagements with artificial companions: Key social, psychological, ethical, and design issues. *Computational Linguistics*, 37(2), 2011.
- [Wil18] Jeremy Wilken. *Angular in action*. Simon and Schuster, 2018.
- [WM20] Robert West and Susan Michie. A brief introduction to the com-b model of behaviour and the prime theory of motivation [v1]. *Qeios*, 2020.
- [WMR17] Sandra Wachter, Brent Mittelstadt, and Chris Russell. Counterfactual explanations without opening the black box: Automated decisions and the gdpr. *Harv. JL & Tech.*, 31:841, 2017.
- [WMZ<sup>+</sup>04] Geoffrey C Williams, Holly A McGregor, Allan Zeldman, Zachary R Freedman, and Edward L Deci. Testing a self-determination theory process model for promoting glycemic control through diabetes self-management. *Health Psychology*, 23(1):58, 2004.
- [WN17] Seth Wynes and Kimberly A Nicholas. The climate mitigation gap: education and government recommendations miss the most effective individual actions. *Environmental Research Letters*, 12(7):074024, 2017.
- [WNP<sup>+</sup>09] Geoffrey C Williams, Christopher P Niemic, Heather Patrick, Richard M Ryan, and Edward L Deci. The importance of supporting autonomy and perceived competence in facilitating long-term tobacco abstinence. *Annals of Behavioral Medicine*, 37(3):315–324, 2009.
- [WOE19] Thomas DW Wilcockson, Ashley M Osborne, and David A Ellis. Digital detox: The effect of smartphone abstinence on mood, anxiety, and craving. *Addictive behaviors*, 99:106013, 2019.

- [WPC21] Lorraine Whitmarsh, Wouter Poortinga, and Stuart Capstick. Behaviour change to address climate change. *Current Opinion in Psychology*, 42:76–81, 2021. Psychology of Climate Change (2021).
- [WS07] Kazuyoshi Wada and Takanori Shibata. Social effects of robot therapy in a care house-change of social network of the residents for two months. In *Proceedings 2007 IEEE international conference on robotics and automation*, pages 1250–1255. IEEE, 2007.
- [WS16] Jessica Fitts Willoughby and Hollie Smith. Communication strategies and new media platforms: exploring the synergistic potential of health and environmental communication. *Science Communication*, 38(4):535–545, 2016.
- [WSB16a] Markus Weinmann, Christoph Schneider, and Jan vom Brocke. Digital nudging. *Business & Information Systems Engineering*, 58(6):433–436, 2016.
- [WSB16b] Markus Weinmann, Christoph Schneider, and Jan vom Brocke. Digital nudging. *Business & Information Systems Engineering*, 58:433–436, 2016.
- [WSMK08] Kazuyoshi Wada, Takanori Shibata, Toshimitsu Musha, and Shin Kimura. Robot therapy for elders affected by dementia. *IEEE Engineering in medicine and biology magazine*, 27(4):53–60, 2008.
- [WWW<sup>+</sup>18] Peng Wang, Peng Wu, Jun Wang, Hung-Lin Chi, and Xiangyu Wang. A critical review of the use of virtual reality in construction engineering education and training. *International journal of environmental research and public health*, 15(6):1204, 2018.
- [WYH03] Massaki Wada, Kang Sup Yoon, and Hideki Hashimoto. Development of advanced parking assistance system. *IEEE Transactions on Industrial Electronics*, 50(1):4–17, 2003.
- [WZD20] Seth Wynes, Jiaying Zhao, and Simon D Donner. How well do people understand the climate impact of individual actions? *Climatic Change*, 162:1521–1534, 2020.
- [Xia13] Wei-Ning Xiang. Working with wicked problems in socio-ecological systems: Awareness, acceptance, and adaptation. *Landscape and Urban Planning*, (110):1–4, 2013.
- [YCFK<sup>+</sup>17] Lai Yen-Chin, YuanLing Feng, Kai Kunze, Junich Shimizu, and Takuro Nakao. Eyewear to make me smile: Can electric muscle stimulation increase happiness? In *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction*, pages 579–582, 2017.

- [YCHS21] Woojin Yoon, Seobin Choi, Hyeseon Han, and Gwanseob Shin. Neck muscular load when using a smartphone while sitting, standing, and walking. *Human factors*, 63(5):868–879, 2021.
- [YDS04] Holly A. Yanco, Jill L. Drury, and Jean Scholtz. Beyond Usability Evaluation: Analysis of Human-Robot Interaction at a Major Robotics Competition. *Human-Computer Interaction*, 19(1-2):117–149, June 2004.
- [YFLL20] Jiaxin Yang, Xi Fu, Xiaoli Liao, and Yamin Li. Association of problematic smartphone use with poor sleep quality, depression, and anxiety: A systematic review and meta-analysis. *Psychiatry research*, 284:112686, 2020.
- [YSSMM12] Neil Yorke-Smith, Shahin Saadati, Karen L Myers, and David N Morley. The design of a proactive personal agent for task management. *International Journal on Artificial Intelligence Tools*, 21(01):1250004, 2012.
- [ZA03] Zacharias Zacharia and O Roger Anderson. The effects of an interactive computer-based simulation prior to performing a laboratory inquiry-based experiment on students’ conceptual understanding of physics. *American Journal of Physics*, 71(6):618–629, 2003.
- [ZHL<sup>+</sup>06] Zhihong Zeng, Yuxiao Hu, Ming Liu, Yun Fu, and Thomas S Huang. Training combination strategy of multi-stream fused hidden markov model for audio-visual affect recognition. In *Proceedings of the 14th ACM international conference on Multimedia*, pages 65–68, 2006.
- [ZvdHE16] Annemarie Zijlema, Elise van den Hoven, and Berry Eggen. Companions: objects accruing value and memories by being a part of our lives. In *Proceedings of the 28th Australian Conference on Computer-Human Interaction*, pages 170–174, 2016.
- [ZWW<sup>+</sup>23] Yifan Zhang, Cheng Wei, Shangyou Wu, Zhengting He, and Wenhao Yu. GeoGPT: Understanding and Processing Geospatial Tasks through An Autonomous GPT, 2023.
- [ZZLQ21] A. Xing Zhu, Fang He Zhao, Peng Liang, and Cheng Zhi Qin. Next generation of GIS: must be easy. *Annals of GIS*, 27:71–86, 2021.



# Supporting Documents

## A.1 Example Interview Guide - Watchful Detox Companion

We appreciate you took the time to participate in our study.

Regarding your overall experience with our digital detoxification prototype, we have a few questions for you. As always, there is nothing you can do wrong! There are no right or wrong responses! We're interested in learning about your personal experience.

We're going to record our conversation with your consent. We will only utilize the recording to understand better what we can learn from your experience and how to make the prototype even better in the future.

1. Which features of the app did you like the most? Why?
2. Which features were most useful for you? How?
3. Which features of the app you did not like? Why?
4. How did your usage pattern change over time during the last 14 days? Why? What was the difference between the first and the second week?
5. Let's begin and briefly talk about the different features of the prototype:
  - Alarm setting and notification (if not already discussed before)
    - Overall impressions
    - Challenges
    - Likes and dislikes
    - Changes they recommend as per their usage

- Usage statistics (if not already discussed before):
  - Overall impressions
  - Challenges
  - Likes and dislikes
  - Changes they recommend as per their usage
- Health data (if not already discussed before):
  - Overall impressions
  - Challenges
  - Likes and dislikes
  - Changes they recommend as per their usage
- How did the usage of the app differ between the smartphone and smartwatch?
- Is there any other feature you think we should implement in the future based on your experience?
- Did anything out of the ordinary occur during last week that would not reflect day-to-day behaviour? (e.g., travelling, vacation, stress at work or exams)
- All that's left for me to say is once more, thank you for taking part! We hope we were able to raise your awareness of your smartphone use.

### A.2 Example Consent Form - Skillab Companion

#### Project Title:

**Skillab - an immersive guide for crafts on the example of floor lamination**

#### Background:

The aim of the study is to understand how an immersive augmented reality environment incorporating muscle actuation technology can aid in completing and learning craftwork skills. The craftwork you are going to learn will be laminating the floor.

#### Procedure:

After handing you the step-by-step floor installation guide and providing you with the material and needed tools, you will laminate the floor with the help of the guide. This guide will walk you through each stage of the process.

When finished, you will be asked to repeat the laminating in a second round without a guide. Finally, you will be asked follow-up questions about your thoughts on the technology and your entire experience.

After you fill out the consent form, you will be given much more information about the study.

**Duration:**

Your participation will not take more than 1 hour.

**Primary Investigators:**

- Florian Michahelles Mobile: xxx, Email: xxx.xx
- Ambika Shahu Mobile: xxx, Email: xxx.xx

**Consent:**

I consent to and understand the following:

Statement	Yes	No
Share images, text, audios, and videos where applicable during the study with the investigators of this study.		
Video and audio are captured.		
The data provided during the study and the recordings may be used by the investigators of this project for related future work and publications.		

By signing this consent form, I also confirm that:

- I do not wear a pacemaker.
- I do not suffer from any heart problems.
- I do not carry any metallic implants.
- I do not suffer from epilepsy.
- I am not pregnant.

**Please fill out the following:**

**Name:** \_\_\_\_\_

**Gender:** \_\_\_\_\_

**Your age:** \_\_\_\_\_

**Your email:** \_\_\_\_\_

**Your signature:** \_\_\_\_\_ **Date:** \_\_\_\_\_

### A.3 Use of AI Tools

This dissertation does not contain any content that was entirely generated by AI. However, AI tools, namely ChatGPT and DeepL, were utilized to support specific aspects of the writing and formatting process. These tools were used to rewrite certain sentences, correct grammar, and generate LaTeX code to format images and tables. The use of these tools was limited to improving clarity, coherence, and presentation, while the research, analysis, and substantive content remain entirely the original work.