MAKING SPACE FOR SELF-CARE:

Designing Virtual Reality Applications to Empower Everyday Well-Being

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To my father.

Abstract

Recent years have seen an increasing preference among individuals to manage their own mental health and well-being, without direct intervention of mental health professionals. Given that one in six people experience mental health challenges at least once in their lifetime, digital solutions could play a critical role in providing autonomous self-care support, both before clinical assistance may be needed and to improve mental health and well-being in everyday life. These so-called self-care technologies (SCTs) can cater to this need as constantly available digital support tools. However, inadequate personalisation possibilities, the failure to create meaningful experiences, and everyday distractions, can present significant barriers to sustained digitally-supported self-care. Among other SCTs, such as wearables or mobile applications, Virtual Reality (VR) stands out for its unique capabilities to address these challenges. It can provide a customisable, distraction-free environment that immerses users in simulated physical spaces while also fostering the necessary mental space, both of which are conducive to self-care.

Recognising that laypeople do not always have a clear idea about the self-care behaviour or strategies they would like to establish, this thesis broadens the range of digital self-care options available to them, with the aim to combine effective outcomes with engaging experiences using VR-based SCT. This work diverges from typical Human-Computer Interaction (HCI) for mental health research, which often examines VR's clinical use such as therapy for anxiety disorders. Instead, this thesis focuses on helping laypeople autonomously manage everyday emotions and challenges for improved mental well-being. Thus, the overall research question to be answered is: How can VR applications be designed to facilitate self-care practices for laypeople in their everyday routines?

In order to address this question, this cumulative dissertation consists of five parts. Part I identifies and describes relevant research gaps in HCI literature,, defines key terminology, and provides background on well-being and self-care concepts relevant to this work. Part II contributes a survey of current design challenges based on a review of VR applications in the consumer market. Part III presents novel approaches to designing the physical space of self-care applications, exploring the impact of different modalities - passive haptics, auditory, and visual - on increasing the understanding of

oneself, a key aspect of self-care. Part IV explores how to integrate support verbal and visual structures and guidance into VR, which can potentially enhance the effectiveness of self-care activities. Finally, Part V discusses the overall findings on a meta-level, presenting key design recommendations and contributing a model that presents specific design ideas that can support the design of effective VR-based self-care applications.

In conclusion, this thesis emphasises the potential of VR as a SCT, providing engaging, supportive, and effective self-care support through the thoughtful design of virtual environments extended by scaffolding elements. Drawing on comprehensive findings of all studies, this work underscores the importance of designing beyond the intervention. It discusses customising options within a single VR application, designing for meaningful experiences over high realism, and optimally balancing engagement with scaffolding elements. This dissertation contributes to a systematic understanding and improvement of VR-based SCT design, forging new paths for HCI research to make space for self-care in their research.

Kurzfassung

In den letzten Jahren zeichnete sich zunehmend der Wunsch ab, die eigene psychische Gesundheit und das mentale Wohlbefinden ohne direkte Expertenintervention autonom zu verwalten. Da jeder sechste Mensch mindestens einmal im Leben psychische Gesundheitsprobleme erlebt, könnten digitale Lösungen eine entscheidende Rolle dabei spielen. Sie können die autonome Selbstfürsorge unterstützen, bevor klinische Hilfe benötigt wird. Zusätzlich ermöglichen es digitale Angebote psychisch stabilen Menschen ihr mentales Wohlbefinden zu erhalten und zu verbessern. Diese sogenannten Selbstfürsorge-Technologien (SCTs) können als ständig verfügbare digitale Anwendungen diesen Bedarf decken. Jedoch begegnen diese Technologien erheblichen Barrieren bei der digital-unterstützten routinemäßigen Selbstfürsorge. Insbesondere unzureichende Personalisierungsmöglichkeiten, das Scheitern an der Erschaffung bedeutungsvoller Erlebnisse und alltägliche Ablenkungen erschweren eine positive Rezeption. Unter verschiedenen Arten der SCTs, wie beispielsweise Smartwatches oder mobilen Applikationen, erscheint die Virtuelle Realität (VR) besonders geeignet,diese Herausforderungen meistern zu können. VR bietet eine personalisierbare und ablenkungsfreie Umgebung, die Nutzende in simulierte Räume eintauchen lässt, aber gleichzeitig den notwendigen mentalen Raum für Selbstfürsorge schaffen kann.

Da Laien mit hoher Wahrscheinlichkeit keine klare Vorstellung von Praktiken und Strategien der Selbstfürsorge haben, die sie etablieren möchten, erweitert diese Arbeit das Spektrum an Optionen für die Zielgruppe. Das Ziel ist, wirksame Ergebnisse und motivierende Erlebnisse mit und durch VR miteinander zu verbinden. Diese Arbeit weicht von der typischen Forschung der Mensch-Computer-Interaktion (HCI) ab, die oft den klinischen Einsatz von VR, wie etwa Therapien für Angststörungen, untersucht. Stattdessen konzentriert sie sich auf die Unterstützung von Laien bei der autonomen Bewältigung alltäglicher Emotionen und Herausforderungen, um ihr mentales Wohlbefinden zu verbessern. Die zentrale Forschungsfrage lautet: Wie können VR-Anwendungen gestaltet werden, um Laien die Selbstfürsorge im Alltag zu erleichtern?

Um die gestellte Frage zu beantworten, besteht diese kumulative Dissertation aus fünf Teilen. Teil I hebt Forschungslücken in der HCI-Literatur hervor, die diese Arbeit adressiert, definiert Schlüsselbegriffe und bietet Hintergrundinformationen zu Konzepten von Wohlbefinden und Selbstfürsorge, die für diese Arbeit relevant sind. Teil II

trägt eine Untersuchung aktueller Herausforderungen im Design bei, die auf Basis einer Analyse von VR-Anwendungen des Verbrauchermarkts aufgestellt werden. Teil III stellt neue Ansätze zur Gestaltung des physischen Raums von Selbstfürsorgeanwendungen vor und erforscht speziell den Einfluss verschiedener Modalitäten - passive Haptik, auditiv und visuell - auf das Verständnis seiner selbst, einem Schlüsselaspekt der Selbstfürsorge. Teil IV erforscht, wie verbale und visuelle Strukturen als Unterstützung in VR integriert werden können, die potenziell die Wirksamkeit von Selbstfürsorgeaktivitäten erhöhen können. Schließlich diskutiert Teil V die Gesamtergebnisse, präsentiert vier wichtige Designempfehlungen und trägt ein Modell bei, das spezifische Designideen vorstellt, wie VR-basierte Selbstfürsorgeanwendungen effektiver gestaltet werden können.

Zusammenfassend betont diese Arbeit das Potenzial von VR als Selbstfürsorgetechnologie, da VR durch die durchdachte Gestaltung virtueller Umgebungen mit unterstützenden Elementen eine ansprechende, bestärkende und effektive Selbstfürsorge bietet. Basierend auf den umfassenden Erkenntnissen aller Studien hebt diese Arbeit praktische Implikationen für die Gestaltung sinnvoller VR-basierter Interventionen hervor. Diese Dissertation trägt zu einem systematischen Verständnis und zur Verbesserung des Designs von VR-basierter Selbstfürsorge bei und ebnet neue Wege für die HCI-Forschung, um Raum für Selbstfürsorge zu schaffen.

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The PhD was a fascinating journey that has shaped me in profound ways. I am humbled to have spent this time amongst great and supportive colleagues, co-authors, friends and family, who have paved the way during this journey.

First and foremost, I would like to thank my supervisors, Johannes Schöning, Yvonne Rogers and Jasmin Niess. To Johannes, for pushing me when I needed it most, for the 3am wake-up calls for sunrise hikes to then be back in the office by 8am, for your endless support throughout my PhD journey, for constantly encouraging me to become a better person, for securing funding for my research, and for always being available to discuss any matter, big or small. To Yvonne, for introducing me to the fascinating topic of mental well-being, for encouraging thoughtful reflection, and for teaching me to take pride in my work. To Jasmin, for being a model mentor, for your thoughtful guidance on everything from experimental design to scientific writing, for helping me navigate the complex landscape of psychology and HCI and for your dedication to spending countless nights providing feedback. Thank you for being both a colleague and a friend, always being there to support me in any way I need, whether it is great advice or just holding a towel.

Special thanks go to Carolin Stellmacher and Evropi Stefanidi. To Caro, for being the best office mate ever, for explaining how colours work, for being an empathetic friend, for sharing rooms on all our good work trips, and for always being there for me whenever I needed to vent or celebrate a milestone. I can't imagine my life without you. To Evropi, who had shared all my lows and highs, who infects me with "coucouness" whenever I need some energy and who is the best person to go hand in hand with through this PhD journey. You really are my PhD soul sister.

To Leon and Ava, my fellow "kids" of the Excellence Chair: thank you for the incredible times we shared, from exploring London's restaurants to racing up and down the stairs to keep awake during our all-nighters before paper deadlines. Your companionship in the Spin Committee and throughout my PhD journey has been invaluable. I couldn't have asked for better colleagues to share this path with.

A heartfelt thank you to Paweł W. Woźniak: You never gave up on explaining the intricacies of quantitative analysis, and thank you for helping me write an entire paper in just an hour before the deadline. To Marit Bentvelzen, for becoming a great friend and ski-sister, and to Matthias Hoppe, for providing VR guidance.

A big thank you to all the great minds I met at Uni Bremen. Thank you, Rainer Malaka, for welcoming me into the DM group with open arms, to Petra and Svenja for their endless patience in guiding me through the bureaucratic jungle, and to Phillip for the unbelievable technical support throughout the years that will never cease to amaze me. Thanks to all my (former) colleagues from Uni Bremen who have become friends, for always sharing knowledge and having an amazing time together: Nima Zargham, Daniel Diethei, Thomas Mildner, Dasha Soroko, Michael Bonfert, and Dimi Alexandrovsky.

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List of Publications

As a cumulative thesis, this dissertation consists of existing work previously submitted and accepted in relevant conferences in the field of Human-Computer Interaction (HCI). All papers that comprise this cumulative dissertation have been authored by me as first author and main contributor of these publications. in cooperation with several collaborators. I am the responsible first author of and main contributor to these publications. Under the supervision and guidance of my advisors Johannes Schöning, Yvonne Rogers and Jasmin Niess, I overall developed the ideas and study designs, devised the techniques, performed the quantitative and qualitative analyses, and discussed my findings of all papers listed below. Yet, as these publications consist of collaborative efforts and in cooperation with several collaborators, specific contributions differ per paper. The list below provides an overview of the publications included in this thesis and lists my specific contribution.

A

Nadine Wagener, Tu Dinh Duong, Johannes Schöning, Yvonne Rogers and Jasmin Niess:

The Role of Mobile and Virtual Reality Applications to Support Well-being: An Expert View and Systematic App Review

Published in *IFIP Conference on Human-Computer Interaction (INTERACT) 2021,* Proceedings, Part IV, Pages 262–283. DOI: 10.1007/978-3-030-85610-6_16
Presented at *INTERACT 2021.*

I conducted the literature review process, being responsible for the identification, screening, and selection of relevant manuscripts, followed by a thorough analysis of the collected corpus. I conducted all interviews, and analysed the findings collaboratively with two co-authors. While one co-author analysed the mobile application review, my role was taking over the application review of all VR applications, including screening and filtering consumer market platforms, and interpreting interpreted the results. I took the lead in drafting the manuscript, rigorously revising it, and overseeing its submission for final publication.

B

Nadine Wagener, Alex Ackermann, Gian-Luca Savino, Bastian Dänekas, Jasmin Niess and Johannes Schöning:

Influence of Passive Haptic and Auditory Feedback on Presence and Mindfulness in Virtual Reality Environments

Published in *Proceedings of the ACM International Conference on Multimodal Interaction (ICMI) 2022,* Pages 558–569. DOI: 10.1145/3536221.3556622
Presented at *ACM International Conference on Multimodal Interaction (ICMI) 2022.*

I conducted the literature review process together with a co-author but being responsible for the identification, screening, and selection of relevant manuscripts, followed by a thorough analysis of the collected corpus. I supervised the study design procedure. While one co-author took the lead of conducting the pre-study, I was leading role when conducting the main study, including running the study, conducting post-test interviews, and analysing its results. Findings were interpreted collaboratively with two co-authors. I took the lead in drafting the manuscript, rigorously revising it, and overseeing its submission for final publication.

C

Nadine Wagener, Marit Bentvelzen, Bastian Dänekas, Paweł W. Woźniak and Jasmin Niess:
VeatherReflect: Employing Weather as Qualitative Representation of Stress Data in Virtual Reality
Published in *Proceedings of the ACM Designing Interactive Systems (DIS) 2023,* Pages 446–458. DOI: 10.1145/3563657.3596125
Presented at *ACM Designing Interactive Systems (DIS) 2023.*

I conducted the literature review process, being responsible for the identification, screening, and selection of relevant manuscripts, followed by a thorough analysis of the collected corpus. Collaboratively with one co-author, I developed the idea, designed the study's procedure, and conducted the study, including running the study, conducting post-test interviews, and analysing its results. Findings were interpreted collaboratively with three co-authors. I took the lead in drafting the manuscript, rigorously revising it, and overseeing its submission for final publication.

D

Nadine Wagener, Jasmin Niess, Yvonne Rogers and Johannes Schöning:
Mood Worlds: A Virtual Environment for Autonomous Emotional Expression
Published in *Proceedings of the ACM Conference on Human Factors in Computing Systems (ACM CHI) 2022,* Article 22, Pages 1–16. DOI: 10.1145/3491102.3501861
Presented at *ACM Conference on Human Factors in Computing Systems (ACM CHI) 2022.*

I conducted the literature review process, being responsible for the identification, screening, and selection of relevant manuscripts, followed by a thorough analysis of the collected corpus. I developed the idea, designed the study's procedure, and conducted the whole study myself, including running the study, conducting post-test interviews, and analysing its results. Findings were interpreted collaboratively with one co-author. I took the lead in drafting the manuscript, rigorously revising it, and overseeing its submission for final publication.

E

Nadine Wagener*, Leon Reicherts*, Nima Zargham, Natalia Bartłomiejczyk, Ava Elizabeth Scott, Katherine Wang, Marit Bentvelzen, Evropi Stefanidi, Thomas Mildner, Yvonne Rogers and Jasmin Niess :

SelVReflect: A Guided VR Experience Fostering Reflection on Personal Challenges

Published in *Proceedings of the ACM Conference on Human Factors in Computing Systems (ACM CHI) 2023,* Article 323, Pages 1–17. DOI: 10.1145/3544548.3580763
Presented at *ACM Conference on Human Factors in Computing Systems (ACM CHI) 2023.*

I shared first authorship with Leon Reicherts. Together, we conducted the literature review process, both being responsible for the identification, screening, and selection of relevant manuscripts, followed by a thorough analysis of the collected corpus. Collaboratively with most co-authors, we developed the idea and designed the study's procedure. I took lead role in conducting the study, including running the study, conducting post-test interviews, and analysing its qualitative results. Quantitative and qualitative findings were interpreted collaboratively with Leon Reicherts. We both drafted the manuscript, rigorously revised it, and I oversaw its submission for final publication.

F

Nadine Wagener, Arne Kiesewetter, Leon Reicherts, Paweł W. Woźniak, Johannes Schöning, Yvonne Rogers and Jasmin Niess:

MoodShaper: A Virtual Reality Experience to Support Managing Negative Emotions

Accepted *Proceedings of the ACM Designing Interactive Systems (DIS) 2024 (in print).*

I conducted the literature review process, being responsible for the identification, screening, and selection of relevant manuscripts, followed by a thorough analysis of the collected corpus. Collaboratively with one co-author, I developed the idea, designed the study's procedure, and conducted the study, including running more than half of the study, conducting post-test interviews, and analysing its results. Findings were interpreted collaboratively with three co-authors. I took the lead in drafting the manuscript, rigorously revising it, and overseeing its submission for final submission.

Complementing Publications

This PhD thesis has not only resulted in the afore-mentioned first-author publications that are part of this thesis. It has allowed me to take part in 12 international conferences, writing 8 workshop papers, co-organising several events such as summer schools and conferences, as well as receiving the Best Doctoral Consortium Presentation Award at IEEE VR 2023. On top of that, this dissertation has generated the following complementing publications, either in first authorship or as contributor, where marked:

– **Nadine Wagener**, Mareike Stamer, Johannes Schöning, and Johannes Tümler. 2020. Investigating Effects and User Preferences of Extra- and Intradiegetic Virtual Reality Questionnaires. In Proceedings of the 26th ACM Symposium on Virtual Reality Software and Technology (VRST '20). Association for Computing Machinery, New York, NY, USA, Article 23, 1–11. https://doi.org/10.1145/3385956.3418972

– **Nadine Wagener**, Johannes Schöning, Yvonne Rogers and Jasmin Niess. 2023. "Letting It Go: Four Design Concepts to Support Emotion Regulation in Virtual Reality," 2023 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), Shanghai, China, 2023, pp. 763-764, https://ieeexplore.ieee.org/abstract/document/10108749

– **Nadine Wagener***, Evropi Stefanidi*, Dustin Augsten, Andy Augsten, Leon Reicherts, Paweł W. Woźniak, Johannes Schöning, Yvonne Rogers and Jasmin Niess. 2024. TeenWorlds: Supporting Emotional Expression for Teenagers with their Parents and Peers through a Multiplayer VR Application. Conditionally accepted to ACM Interaction Design and Children (IDC) 2024. *shared first-authorship

– **Nadine Wagener**, Bastian Dänekas, Meagan B. Loerakker, Paweł W. Woźniak and Jasmin Niess. 2024. Light Me Up! Ambient Light Increases Heart Rate and Perceived Exertion during High-Intensity Virtual Reality Exergaming. Submitted to NordiCHI 2024.

– Carolin Stellmacher, Florian Mathis, Yannick Weiss, Meagan B. Loerakker, **Nadine Wagener** and Johannes Schöning. 2024. Exploring Mobile Devices as Haptic Interfaces for Mixed Reality. 2024. In Proceedings of the CHI Conference on Human Factors in Computing Systems (CHI '24), May 11–16, 2024, Honolulu,

HI, USA. ACM, New York, NY, USA, 17 pages.
https://doi.org/10.1145/3613904.3642176

– Evropi Stefanidi, **Nadine Wagener**, Ioannis Chatzakis, Paweł W. Woźniak, Stavroula Ntoa, George Margetis, Yvonne Rogers and Jasmin Niess. 2024. Supporting Communication and Well-being with a Multi-Stakeholder Mobile App: Lessons Learned from A Field Study with ADHD Children and their Caregivers. Conditionally accepted to CSCW 2024.

– Ava Elizabeth Scott, Leon Reicherts, Aditya Kumar Purohit, Elahi Hossain, Evropi Stefanidi, **Nadine Wagener**, Johannes Schöning, Yvonne Rogers and Adrian Holzer. 2024. DIY Digital Interventions: Behaviour Change with Trigger-Action Programming. Conditionally accepted to Mobile HCI 2024.

– Julian Rasch, Michelle Johanna Zender, Sophia Sakel and **Nadine Wagener**. 2024. Mind Mansion: Exploring Metaphorical Interactions to Engage with Negative Thoughts in Virtual Reality. Conditionally accepted to ACM Designing Interactive Systems (DIS) 2024.

Part I

INTRODUCTION & BACKGROUND

1 Introduction

1.1 Motivation

A prevailing vision of mental health care is sitting on an old dusty couch in an office behind closed doors, talking to a therapist about one's emotions. However, technologies that aim to promote self-care, called self-care technologies (SCTs), have changed how we think about and take care of our mental health. Nowadays, there are many SCTs available, including smartwatches, smartphone applications and video tutorials [551]. They are designed to accompany people throughout the day, from reviewing their sleep data in the morning to a guided relaxation activity in the evening. They aspire to personalise tracking, motivate people to be more active, provide the means to relax, or teach skills that can be used to help people constantly improve themselves.

The rising number of interactive technologies and digital services targeting mental health, well-being and self-care, have led to them becoming an important topic in a wider public discourse [249, 585]. People are becoming more proactive in exploring and applying self-care themselves [249, 585], aiming to recover, maintain and improve their physical and mental health or well-being in an autonomous manner [99, 655]. For example, in 2022, one-quarter of Americans stated that they intend to improve their mental health and self-care [393] and to achieve this, many turned towards digital solutions for autonomous mental health management in their everyday routine [128, 542, 604].

Despite — or perhaps correlated with — the growing interest in autonomous self-care, there is an observed increase in mental distress across various cultures and backgrounds [424]. Statistically, one in six people will experience mental health challenges at least once in their lifetime [18]. Modern fast-paced lifestyles are contributing to a general decline in mental health [636], with many experiencing conditions such as anxiety and stress. For instance, in 2022, 58% of Americans reported self-diagnosing poor mental health conditions [393]. Similarly, in Germany, there was a significant decline in mental health from 2019 to 2023, with approximately 60% of individuals noting a deterioration in their mental well-being [615].

Thus, SCTs are being increasingly developed to try to reduce the burden on overextended healthcare systems [424], diminishing the waiting time for professional treatment [445] and by offering complementing therapy [39], although digital technologies cannot substitute treatment by experts [128]. Moreover, SCTs can offer new opportunities to deliver mental health and well-being support to mentally stable people at home who do not need clinical treatment but are interested in taking care of themselves [164]. As cost-effective and convenient everyday technologies, they extend access to self-care support to a broader population than traditional face-to-face interventions [39], including reaching individuals in rural areas [51].

Most relevant to this dissertation, SCTs also offer personally tailored support and context for self-guided help, empowering individuals to manage their own care effectively [392, 495]. SCTs can promote self-care activities for physical, social, emotional and cognitive development, for increasing self-awareness and for learning how to provide space in their everyday lives for taking care of their own needs [99]. This concept of proactively taking care of one's own mental health in a non-clinical setting, with the aim of being able to meet everyday challenges, is termed *mental well-being* [98], core to this dissertation.

Despite the huge potential of SCTs for providing autonomous mental well-being management, they often struggle with overcoming certain barriers to self-care use. A common barrier of SCTs is a lack of personalisation [405]. The design of SCTs has to meet an immense variety of very specific user needs and diverse backgrounds to create effective self-care support [86, 405]. Lack of customising options can result in failing to create meaningfulness, which can diminish the potential for continued use [86, 551]. Moreover, users often lapse in usage because of lack of time, reduced self-motivation, unsuccessful integration in routines and habits, or forgetting to use them due to everyday distractions [405]. To address these barriers, novel techniques and a broader range of self-care activities promoted by SCTs are needed to provide engaging and effective self-care to a broad range of very diverse people.

One technology that is underresearched so far in its potential to address some of these challenges and provide personalised and engaging self-care support is Virtual Reality (VR). VR stands out as a promising SCT among other technologies due to the following reasons: It completely insulates users from real-world distractions, as it simulates real-life situations through 3D computer-generated immersive environments [368]. These immersive environments can be manipulated in nuanced ways to create meaningful interventions [330, 423]. For instance, they can be made more realistic through the inclusion of various modalities such as visual elements and auditive and tactile feedback [350], which can provide a mental focus on the virtual environment, making people forget reality for the time being, called presence [264]. Increased presence can enhance the effectiveness of some self-care activities, for example mindfulness exercises [389]. Further, it provides much potential for customising a virtual environment so that it can be tailored towards personal preferences. It also enables creative expression through dynamic elements and metaphoric actions that are unique to this medium and difficult to replicate in reality or with other technologies (e.g. [89, 225]). Consequently, VR can potentially motivate people to invest time and focus on engaging in self-care activities. It offers unique capabilities to simulate safe spaces and provide guidance, presenting new alternatives to the prevailing traditional vision of well-being support, often involving sitting on couches in closed rooms and discussing personal problems with therapists.

Despite VR's potential, considering the current research landscape for VR-based SCT, much research has concentrated on specific therapeutic outcomes. Most well-known is the aim to reduce unwanted symptoms or emotions. To that end, VR has become famous for its applicability in exposure therapy since the 1990s. Hereby, the controllability of VR is leveraged to confront users with their phobias, gradually increasing the fearful stimuli [475]. Renowned in that regard is the so-called 'plank experiment', in which users are asked to balance along on a physical plank that, in reality, is only few inches off the ground, but seems to be in great height in VR [365]. However, more recently, the focus on exposure therapy was criticised [538]. In 2022, a review showed that still more than 50% of examined HCI research focuses on exposure therapy, disregarding other self-care features such as providing psycho-education and promoting cognitive change [340]. This underscores a persistent narrow focus in the field in regard to VR-based SCT.

Besides exposure therapy, there has been a notable emphasis on positive psychology (e.g. [290]), providing hedonic experiences, meaning focusing on eliciting pleasure and relaxation [254]. The most renowned in that regard is mindfulness-based stress reduction (MBSR) [601]. Hereby, VR applications mainly aim to reactively reduce stress felt from everyday life and increase relaxation [435, 459], provide a pleasurable (hedonic) experience [388, 440], and thus strengthen the resilience against future stressors [521]. MBSR using VR, overall, is very successful [21], which is as also reflected by the large consumer market that has evolved to provide MBSR [62, 557]. While beneficial, MBSR only represents a portion of the potential spectrum of the utility of VR-based SCT.

In comparison, less research focuses on other forms of self-care. For example, Baumer [46] and Jiang and Ahmadpour [266] found that only few applications specifically target self-reflection as a self-care activity. Further, it is criticised that many focus on what information to provide, instead of facilitating the development of suitable skills which can be practised in a safe environment such as VR [540].

Consequently, this dissertation diverges from these conventional paths. It specifically addresses the design of VR as SCT '*beyond specific practices*', prioritising the enhancement of user autonomy in managing their own self-care. This approach emphasises the empowerment of users to proactively engage in self-care, doing justice to the mix of multifaceted experiences of everyday life. Adopting this holistic perspective, this work integrates VR approaches that target skill development and self-care practices for negative emotions and experiences, albeit not exposure therapy, as well as creating pleasurable experiences eliciting positive emotions. This broader scope allows for a more nuanced understanding of VR's role in self-care, moving beyond reactive therapeutic or stress resilience support.

Additionally, this dissertation strongly focuses on *laypeople* as a target group. Laypeople, in this dissertation, is used to refer to individuals who do not have formal training in self-care practices, who are unguided and unsupervised by mental health professionals and instead choose to engage in self-care activities independently [638]. They may encounter several challenges throughout their self-care journey: lacking awareness of their specific needs [135], not possessing the necessary vocabulary to select the most appropriate self-care application [135], and representing a target group with vast variations in needs, cultural backgrounds, and personal preferences [86].

They may encounter several challenges throughout their self-care journey: they may lack awareness of their specific needs [135], they might not possess the necessary vocabulary to select the most appropriate self-care application to match their needs [135], and this target group includes people with vast variations in needs, (cultural) backgrounds, and personal preferences [86]. Given this diversity and considering that people face many different mental health challenges throughout their lives, it can be helpful to provide them with a variety of different options and strategies to learn how to navigate everyday challenging situations.

This also involves considering how best to a design for an effective outcome with engagement, as keeping people motivated for continued use of the application, or to at least continue self-care, is essential [135]. It is assumed that sustained and regular practise of self-care and integration of self-care behaviour into daily life can help to better manage anxiety at work or stressful family situations while minimising risks of developing mental disorders which can be exacerbated by everyday challenges [99, 655]. However, the question remains how best to design VR-based SCT that is effective while being fun and engaging. This dissertation seeks to uncover how VR can best accomplish this.

In sum, this thesis examines how the unique affordances of VR can be operationalised to meet the open-ended and varied self-care needs of untrained users in an engaging way. Given this picture, the following central research question drives this research: **Central RQ**: **How can VR applications be designed to facilitate self-care practices for everyday mental well-being?**

1.2 Research Questions & Methodology

To re-iterate, this thesis explores the design space of VR interventions that aim to provide activities to foster self-care in a multitude of ways. Thereby, self-care is defined as intentional actions undertaken by laypeople to take care of their well-being, involving emotional and cognitive development [99]. By leveraging the affordances of VR, first and foremost through an autonomous customisable design of VR environments, the goal is to provide engaging and effective self-care experiences for laypeople, who may not necessarily have (psychological) pre-knowledge of effective self-care strategies. While findings might be transferable to clinical settings, this thesis aims to support the increasing number of people who are interested in autonomous self-care in an everyday setting and targeting managing everyday challenges [249, 585].

The next section outlines the three research questions that were posed, each with a distinct focus. This is followed by a description of the methodologies used to explore these research questions in the published papers. The specific contribution of this thesis to the field of HCI is next. An ethics statement is presented explaining the ethical methodological approach adopted throughout the dissertation. This section ends by providing a list of terminology used throughout the thesis and a detailed thesis outline.

1.2.1 Formulation of Research Questions

The central RQ, **How can VR applications be designed to facilitate self-care practices for everyday mental well-being?** is divided into three research questions that are motivated in detail in the following sections. In short, first, there is limited knowledge of the key design challenges associated with self-care design for laypeople, especially considering specific features of VR-based SCT to provide effective, safe and engaging experiences for laypeople [135]. Thus, RQ1 addresses this research gap by providing an application review of VR-based SCT available in the consumer market. Second, based on basic perception theory [306], philosophical considerations of technology design [596] and research of the influence of the virtual space on emotions (e.g. [155, 227]) and behaviour (e.g. [349, 618]), it is hypothesised that the virtual space impacts self-care objectives, in particular becoming aware of emotions or thoughts, which is called

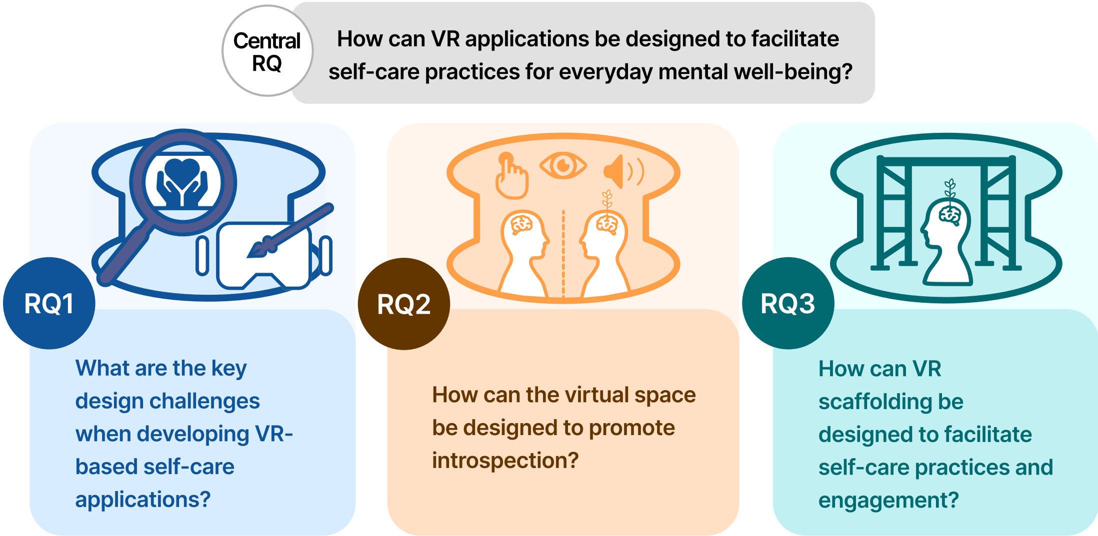

Figure 1.1: Overview of Research Questions.

"internal states" [442]. Thus, the impact of features and modalities in the design space of the virtual environment is explored, addressing RQ2. Third, psychological research suggests that people need the capacity, motivation and outside encouragement to learn skills for self-care [54, 539]. This outside encouragement, called scaffolding, could potentially enhance the effectiveness of SCTs. However, so far it remains under-researched how VR can provide scaffolding, being addressed in RQ3. The research questions are illustrated in Figure 1.1.

Exploring the Key Design Challenges

When considering this broad user group, the great diversity of needs and backgrounds becomes obvious [86]. The market for mental health and well-being applications has exploded; hundreds of VR applications promise self-care support in some form or other [62, 580], as mental health and well-being are considered multifaceted and holistic topics (see Section 2.2). Yet, as limited knowledge is one of the key challenges associated with self-care for laypeople [135], they may not know the terminology to search for specific applications for practices such as 'mindful meditation'.

When looking for a VR application for well-being, laypeople often turn to digital international marketplaces like Steam or Oculus [432]. However, the consumer market for VR applications on Steam predominantly features gaming-oriented VR applications, with 51% classified as action games, and 40% as casual games [557]. This shows that there is a relative scarcity of SCTs, which makes finding self-care and mental well-being applications more challenging. Additionally, research indicates a lack of cohesive classification for commercial VR offerings on Steam and a notable absence of external regulatory classifications [198, 199]. This complicates searching for suitable self-care VR applications for laypeople, especially as they often lack specific knowledge, terminology and motivation [135]. When conducting a quick search for VR self-care applications on Steam in 2021, using only the terms 'mental health' AND|OR 'mental well-being' and filtering for categories such as 'Health & Fitness', 'Medical' and 'Lifestyle', it came up with close to a 1000 hits. Yet, a number of those included violent content and horror games. Similar experiences were reported in a review of consumer apps by Thunström et al. [580]. Therefore, there is a need to help people learn how to find applications that are a good match for their needs. How can this area be made safe?

Literature is scarce in terms of systematic reviews investigating features, specific design elements, and the self-therapeutical potential of consumer VR applications on commercial platforms. Only two recent reviews conducted by Best et al. [62] and by Thunström et al. [580] for commercial VR applications in the area of mental health and well-being were found [557]. However, they did not investigate specific design features, rather focusing on a general market analysis. Similarly, [432] also analysed the VR consumer market for mental health potential on a meta-level. Other reviews, such as from [321] or [119] analysed applications not in the consumer market but from HCI research. Moreover, Pira et al. [321] in regard to genre cover severe mental health issues, and while Cheng et al. [119] included well-being, they focus on gamification elements within VR self-care applications. Other research has focused more on general SCT design (e.g. [164, 551]), not specifying on VR as technology. The lack of systematic research on specific design features, potentials and risks of VR applications available in the consumer market motivated the first RQ.

In addition, it is important to tap into the expertise of different stakeholders, including mental health professionals who can be considered experts when assessing potentials, risks and safety issues related to autonomous self-care in an everyday context. Their practical insights into therapeutic processes can help guide the development of VR technologies that address specific mental health issues. This approach aligns with the Human-Centered Design (HCD) principle [4], and suggestions to include stakeholders for all steps when designing SCTs [596]. Their involvement can also help in the evaluation of commercially available applications. For example, a panel of experts with different expertise rated the therapeutic potential of 50 freely available VR applications from the consumer market, only deeming 22% of them fit to assist in everyday self-care [62]. Additionally, therapists were included in the design process of several symptom-specific

VR applications, for example for psychosis [294] and eating disorders [353]. By leveraging expert knowledge, current key design challenges and research gaps can be derived especially for VR applications catering to the broad needs of individuals without severe mental health issues seeking autonomous self-care activities. To this end, a systematic analysis of existing consumer technologies available to lay users was initially conducted. It was intended to answer the following research question:

$\mathbf{RQ_1}$: What are the key design challenges when developing Virtual Reality-based self-care applications?

To explore, we conducted a systematic application review of features of VR applications available in the consumer market. As an understanding lens, we compared their design with expert knowledge from psychotherapists. In in-depth interviews, experts shared their understanding of therapeutic practice and expectations on how VR-based SCT should provide self-care. We then identified any potential mismatches, which highlighted current research gaps. Further, this research presents key requirements and overall design recommendations for VR-based SCTs. The result of this investigation was a survey paper called *The Role of Mobile and Virtual Reality Applications to Support Well-being: An Expert View and Systematic App Review* published at Interact in 2021. Throughout the dissertation, I refer to this paper as paper *A - AppSurvey* in short.

Inside-Out – Exploring the Design of the Virtual Space

A major component of self-care is becoming aware of internal states [32], of consciously understanding and processing emotions, thoughts and beliefs [458]. Self-awareness can be an outcome of various self-care activities. The practice of engaging in self-care activities that bring subconscious and previously unnoticed internal states to conscious awareness is what I term the *Inside-Out approach*. In other words, the Inside-Out process describes opening one's inner world to the outside, effectively externalising internal states and transforming them into something observable and shareable with oneself or others.

However, the process of becoming self-aware is challenging, with many people finding it difficult to consciously comprehend their internal states at any given moment [454]. To promote the Inside-Out process, VR bears great potential. For instance, it provides a distinct '*head-space*' by shielding people from the never-ending distractions of reality and immersing them in alternative worlds, thereby fostering a sense of presence of forgetting the real environment for a moment [536]. Presence is commonly known to make self-care more effective, positively influencing mindfulness practice [389, 513], agency [267], emotions [267, 462] and general user experience [504, 571].

Further, users are immersed in '*physical virtual spaces*', which are hypothesised to be able to promote self-awareness. Prior research has shown that environments can subtly influence one's behaviours and perceptions, often without users' conscious awareness [349, 618]. Additionally, people continuously re-interpret the environmental stimuli, as explained by basic perception theory [306], which plays a crucial role in shaping their self-perception and directing their focus. For instance, colour [468] and elements in motion [433] draw people's attention, while the general scene, including lighting, auditive elements, and surrounding landscape, can have an emotionally arousing (e.g. [603] or calming effect (e.g. [155, 227]). This suggests that design decisions regarding the virtual space hold the potential to facilitate self-awareness by eliciting desired states of arousal as well as drawing the focus to certain elements or even encouraging an inward focus of attention.

To that end, prior research has noted that highly realistic virtual environments facilitate presence [536], and thus it is hypothesised that it also positively affects self-awareness. To create realism, most research in HCI places the focus on visual aspects of VR [593]. This is logical considering that the visual system is the brain's primary source of information that shapes our interpretation of the world [306]. Besides using high-realistic environments for relaxation purposes (e.g. [227]), one particular trend of SCTs is to use visualisations to promote reflection [405]. Visualisation is hereby defined as an interactive visual representation of data that is computer-supported with the aim to augment cognition [110]. Visualisations were found to strengthen engagement and facilitate reflection of data [189], for instance when biosignals such as heart rate are presented in an alternative qualitative way [405]. [110] emphasise that the goal of visualisation is not to produce aesthetically pleasing charts but rather to enable people to gain new knowledge. However, the exploration of visualisations in VR is under-researched, particularly using virtual visual elements to represent health data or internal states. This research gap motivates a deeper examination of how visual stimuli within VR can influence self-awareness as part of RQ2.

Less explored is the impact of audio on self-care, particularly self-awareness. It is well-known that music and ambient sounds in VR can greatly influence people's emotions [433]. They can increase presence through isolating users [159] but also distract from study goals [380]. Thus, the role of sound in establishing realistic environments and its potential influence on the process of self-awareness has yet to be clearly defined, as addressed in RQ2.

Additionally, in regard to creating realism, it is criticised that most high-realistic virtual environments lack the integration of some sensory cues that people use in reality, such as touch perception, also called haptic feedback [315]. Haptics has been mostly overlooked due to methodological challenges [593]. Further, Neo et al. [391] point out that VR designers need to carefully balance the integration of real elements into the VR to generate feedback that enhances presence. For instance, haptic and auditory feedback can either enhance realism and beneficially help isolate viewers from the real world [159], but might also distract and diminish the effectiveness of the study goal [380]. Nonetheless, haptic feedback can aid in designing a truly immersive experience as it requires a direct interaction between user and virtual elements, providing sensory feedback about temperature, texture and rigidity [593]. Thus, missing haptics might trigger a mismatch between tactile and visual perception, called visual-haptic conflict [264], which can result in mental confusion and reduction of presence [264]. A question that remains unexplored so far is the extent to which haptic feedback can contribute to self-awareness by enriching the virtual environment's realism, motivating RQ 2.

Therefore, design choices in the virtual environment are crucial, as they can significantly improve the efficacy of self-care activities. Specifically, decisions about which modalities to incorporate and how to integrate them are key to boosting presence and enabling self-awareness.

These considerations suggest that the virtual space needs to be carefully designed, as it could potentially improve the effectiveness of self-care activities, in particular self-awareness. Specifically, decisions about which modalities to incorporate and how to integrate them can be key to increasing presence and facilitating self-awareness. Therefore, this part of this thesis aims to illustrate the following research question:

$\mathbf{RQ_2}$: How can the virtual space be designed to promote introspection?

To address RQ2, three user studies were conducted. The first study examined the effects of haptic and auditory feedback in VR. It explored the impact of multimodal stimuli, including tactile feedback through passive haptics and ground-adaptive footstep sounds. The study assessed the effects of multimodality on self-awareness and presence during walking and mindfulness tasks in VR. This work resulted in a paper entitled *Influence of Passive Haptic and Auditory Feedback on Presence and Mindfulness in Virtual Reality Environments* and was published at ICMI 2022. This dissertation refers to this paper as paper *B - Haptics* in short.

The second study assessed the combination of visual and auditory elements for self-awareness, in particular for visualising and facilitating the understanding of stress-related health data. Participants' stress levels were measured using a smartwatch and presented either as quantitative data in a 2D plot or qualitatively through immersive weather scenarios including visuals (e.g. lightning, sun) and sound (e.g. thunder, birds' chirping). The study evaluates the impact of these modalities on user engagement, understanding, and reflection on health data. The results were published in a paper called *VeatherReflect: Employing Weather as Qualitative Representation of Stress Data in Virtual Reality* at DIS 2023. This paper is abbreviated as paper *C - VeatherReflect* throughout the thesis.

The third study investigated the impact of visual elements on self-awareness for visualising internal states. Participants were provided with a set of VR drawing tools that they used to create personalised virtual environments representing a safe space for them. The study explored how using VR drawing can foster self-care, understanding of one's internal states, emotional engagement, and well-being, employing an exploratory approach due to its innovative nature. The work was written up as a paper called *Mood Worlds: A Virtual Environment for Autonomous Emotional Expression* and was published at CHI 2022. This paper is abbreviated as paper *D - MoodWorlds* throughout the thesis.

Outside-In – Exploring the Design of Scaffolding

This section is motivated partly by related works and partly by the findings of the previous studies. Key challenges that laypeople face are missing knowledge, lack of motivation or their lifestyle clashing with their motivation for self-care [135]. Psychological research suggests that people need the capacity and the motivation to learn skills necessary for self-awareness [54]. For example, Slovak et al. [539] found that learning the skill of reflection can be a challenging activity and often needs to be encouraged from the outside, either through other people such as therapists or family and friends, or through technologies.

Nudges from the outside are called *scaffolding* which provides a framework, support and guidance intended to help people complete a task or learn a skill independently [54]. If technologies provide these nudges, it is called computer-based scaffolding [54]. A key question is how VR can provide scaffolding that enhances the effectiveness of self-care through guiding skill learning, but at the same time leaves enough room for engagement and autonomous well-being management. The third part of the thesis thus focuses on how VR applications can be designed to nudge users from the outside to become more aware of their internal states, reflect on personal challenges, and guide emotion regulation processes. We call this the *Outside-In approach*.

To that end, the research of Part III drew inspiration from different types and methods of scaffolding used in therapeutic practice. For instance, voice is used as a mode of scaffolding to ask reflection-enhancing questions and prompt certain behaviours, a well-known technique used in therapy and when talking to friends and family [54]. Although conversational interfaces or chatbots have been recognised for their potential to offer voice-based scaffolding for mental health and self-care [203, 371], and particularly in facilitating self-awareness [318], research exploring the integration of these interfaces within VR remains limited. Most research in that regard, for example, [377] and [643], do not focus on complex self-care-related tasks, informing RQ3.

Furthermore, philosophical considerations of technology's design emphasise that technologies, when designed effectively, can influence people's perception of the world and themselves, as well as prompt certain behaviour, without needing to ask questions out loud [595]. For example, speed bumps prompt car drivers to slow down. Similarly, therapeutic practice uses visual means to scaffold certain perceptions and stimulate cognitive restructuring and externalisation [446]. Oftentimes, in psychotherapy, negative thoughts or emotions are thereby visualised and objectified [89]. Yet, it is still to be determined how VR can incorporate comparable visual tools to assist users on their self-care journey, enabling skill acquisition and reflection.

This informs the next research question:

RQ$_3$: How can VR scaffolding be designed to facilitate self-care practices and engagement?

Two user studies were conducted to answer this research question. The first study explored the effects of integrating verbal scaffolding in VR. Voice-based prompts were embedded in a VR setting to facilitate self-reflection, with the aim of encouraging users to express and analyse a personal challenge that had been worrying them. The prompts were designed to guide users to deconstruct their challenges into smaller stages, reinterpret the importance of social relationships, and explore new coping strategies for everyday challenges. The study was inspired by the findings of previous research that has shown how conversational interfaces such as chatbots can scaffold users through complex tasks [452, 451, 630]. The study was written up as a paper called *SelVReflect: A Guided VR Experience Fostering Reflection on Personal Challenges* and was published at CHI 2023. This paper is abbreviated as paper *E - SelVReflect* throughout the thesis.

The second study followed on from this line of research by exploring how scaffolding can help laypeople regulate and reflect on their everyday negative emotions, albeit using visual scaffolding. Again drawing inspiration from therapeutic self-care practices, three interventions were developed to enable users to visually manipulate representations of negative emotions in VR. Adopting an exploratory approach, participants interacted with one strategy while viewing demonstrations of the other interventions for comparison. This research was documented in a paper titled *MoodShaper: A Virtual Reality Experience to Support Managing Negative Emotions* and is currently in print at DIS 2024. This paper is abbreviated as paper *F* - *MoodShaper* throughout the thesis.

Table 1.1: Summary of the publications arising from the research conducted in this thesis; in terms of the main problems and research gaps, findings and corresponding research questions.

Problem Definition	**RQ**	**Papers**
The current understanding of features, potentials, and risks of VR apps in the consumer market designed to support self-care for untrained users lacks clarity. Incorporating expert insights is crucial for establishing guidelines and (safety) requirements, yet there is insufficient existing research aligned with my research goals.	What are the key design challenges when developing Virtual Reality-based self-care applications?	A
Many people find it challenging to consciously comprehend their internal states [454]. VR has the potential to offer a distinct 'head-space' as well as suited 'physical virtual space' to facilitate self-awareness, yet, more research is needed to explore how to best leverage unique VR affordances in regard to designing this space. VR often lacks the integration of sensory cues that people use in reality [315] but great need for careful balancing of those [391].	How can the virtual space be designed to promote introspection?	B, C, D
People need the capacity and willingness for self-awareness [54]. People need extrinsic motivation and encouragement for self-care practices [539]. Previous study participants have indicated a strong preference for increased guidance and support.	How can VR scaffolding be designed to facilitate self-care practices and engagement?	E, F

1.2.2 Research Methodology

A human-centred design process (HCDP) was adopted throughout the thesis when considering how to design and evaluate VR applications for self-care and mental well-being, adhering to the ISO 9241-210 norm. This involves developing for and with users, including all stakeholders, and striving to ensure that the design optimally fits to user needs, thereby mitigating risks of using the technology in a wrong way or entirely refraining from usage [96]. It can also enhance the user experience and user productivity, facilitating intuitive interaction, and reducing stress and discomfort, in particular when researching sensitive and emotionally charged topics as is the case in this dissertation [96].

To begin, the research developed an understanding of the users' context, employing a survey to achieve this (see paper *A - AppSurvey*). The use of the survey method provided a way of finding common ground among self-care stakeholders such as psychotherapists, users, VR designers and researchers. It overall fosters an informed design process and ensures that design solutions are relevant and tailored to the actual needs and expectations of all parties involved. The systematic review of consumer applications was combined with in-depth interviews with psychotherapists to focus in more detail on specific features that were considered important. Hence, the method used in paper *A - AppSurvey* examined experts' expectations and guidelines for self-care from a broad perspective evaluating users' needs and research gaps from the current design.

The subsequent phase of the HCDP is based on requirement elicitation to capture the nuanced needs of users, building on literature reviews and theory-informed design decisions. This method allows having the user and their needs at the forefront of design decisions with the benefits of HCD [96] while also learning from insights of prior work [595]. Moreover, the inclusion of users and participants in the elicitation phase, through workshops, interviews or pre-studies, can capture specific user requirements directly from the intended audience, ensuring that the design is human-centric, and can create engaging and personally meaningful interventions [647]. Arsand et al. [22] emphasise the importance of this approach in the context of designing SCTs.

Consequently, users and psychotherapists were integrated in the requirement elicitation phase in manifold ways across publications. In paper *D - MoodWorlds*, participants took part in a pre-study, where they were asked to analogously draw emotional mood boards, which were then analysed using thematic analysis to serve as inspiration for the creation of the resulting VR application. In addition, interviews were conducted to find out the most important features and the overall user experience when visualising emotions, which refined design decisions for the resulting VR self-care application as presented in *D - MoodWorlds*. In paper *E - SelVReflect*, a co-design focus group was held to establish requirements for the verbal scaffolding used afterwards as part of the VR guidance. Further, psychotherapists were asked to share therapeutic practices in semi-structured interviews that led to the generation of design ideas for self-care (reported in papers *A - AppSurvey* and *F - MoodShaper*).

Based on the insights gathered from the context and elicitation phases, prototypes were designed and built through iterative cycles. This process, characterised by multiple testing phases and user feedback loops, ensures that the designs were developed to meet user expectations. This iterative approach was applied across all VR self-care activities discussed in this thesis (papers B, C, D, E, F).

The next step involved the evaluation of the prototypes. A number of user studies were conducted (reported in papers B, C, D, E, and F). For the sake of clarity, the evaluation phase is presented in two parts: conducting the studies and evaluating their outcomes. Many studies are conducted within labs to ensure comparability of findings. In contrast, field employment, also called "in-the-wild studies", offer insights into how technology integrates into users' lives [473]. A hybrid study setup, as suggested by Ratcliffe [448], combines the benefits of both, balancing controlled environments with real-world applicability, and was implemented in papers *D - MoodWorlds* and *F - MoodShaper*.

To evaluate the findings from the user studies, qualitative research methods and thematic analysis were employed across all papers. Qualitative research, as emphasised by Mertens and Creswell [140], is particularly suited for delving into the complex phenomenon of self-care. The thematic analysis followed the methodological approach of Braun and Clarke [83, 84], and guidance of Blandford [67]. This allowed for the identification of patterns and themes that emerged from the participants' narratives, providing insights into their experiences with self-care and the designed VR interventions. In so doing, a rigorous and thoughtful analysis of the qualitative data ensued, resulting in a deep understanding of the perceived participant user experience.

While qualitative data offers rich, detailed narratives about users' experiences and perceptions [140], quantitative data provides measurable, comparable insights that can help to confirm or challenge the qualitative findings, as well as allowing for comparability across studies and research teams, which enhances transparency and validity of results [223]. Hence, some of the studies reported in the publications used a combination of qualitative and quantitative analyses. Data for the latter was collected through standardised and validated questionnaires and data logging. This mixed-method approach added to the breadth and depth of understanding, triangulating data and the validity and reliability of the findings [223]. Papers *B - Haptics*, *C - VeatherReflect*, *D - MoodWorlds*, *E - SelVReflect*, and *F - MoodShaper* use a mixed-method approach. Measurements were typically taken before and after the VR interventions, enabling an assessment of emotional and cognitive changes attributable to the intervention.

Each publication within this thesis contributes to the overarching research aim of how to design VR applications to facilitate self-care practices in daily life. Notably, each paper in itself exemplifies the HCD process in action. This iterative cycle of understanding, design, and (re-)evaluation ensures continuous improvement and relevance of the design recommendations that I derive from my work.

1.2.3 Contributions to Human-Computer Interaction

This thesis is situated in the third wave of HCI. This means that *humans* are defined as persons engaged in socio-cultural practices, *computers* are viewed as any technological system, including VR, and *interaction* is seen as the experience of using a system for meaningful practice [45].

The contributions of this thesis to the field of HCI are several as can be seen in the publications arising from the work conducted. They are classified according to [633]. First of all, this thesis contributes the findings of an extensive survey (paper *A - AppSurvey*). The meta-review revealed current trends of self-care VR applications that are available in the consumer market, and by comparing the features that are currently presented with expectations from experts in regard to effective and safe mental well-being support, sheds light on to-be addressed research gaps. This review of the state of the art is intended to be used by other researchers and designers when considering how to design new self care apps for consumers in the context of mobile and VR applications.

Further, I contribute empirical knowledge with all the publications reported here (A-F) with the exploration and observation of scientific discovery-driven activities, generating and evaluating new hypotheses [633]. Based on the findings of the mixed method methodology, including surveys (A), interviews (A, B, C, D, E, F), user studies (B, C, D, E, F), focus groups (E), and hybrid evaluation settings (D, F), a diversity of new knowledge was provided.

Additionally, I created five interactive artefacts through generative design-driven interventions (B, C, D, E, F) [633]. I designed new VR systems for self-care, that were fully deployed as prototypes. They were able to demonstrate how to provide self-care activities, facilitating self-exploration and fostering self-knowledge, and in so doing increasing mental well-being. The artefacts were designed to support mindfulness practice (B), self-reflection (C, E), self-expression (D, E, F) and emotion regulation (F).

All the artefacts were iteratively designed and evaluated with users.

Finally, a tailored set of design recommendations for VR applications are presented that focus on enhancing self-care. Significantly, these guidelines are applicable not only to VR applications adopting a similar approach to the ones outlined in this thesis but also to those employing different methodologies and strategies to support self-care. Therefore, the insights gathered through this work will benefit future HCI research when designing VR applications that foster autonomy and support self-care.

1.2.4 Ethics Statement

I recognise the complexities involved in engaging participants on sensitive topics, which might trigger negative emotions and/or recall of distressing memories. This research illustrates both the inherent challenges and the potential benefits of such studies, demonstrating the feasibility and positive impact of these endeavours. Consequently, all studies that deal with a potentially harmful matter (such as eliciting negative emotions) have received ethical clearance from university ethics boards, in line with the Declaration of Helsinki (*E* - *SelVReflect*: University College London, *F* - *MoodShaper*: HSG-EC-20220503). Ethical clearance ensured that all user studies were carried out with participants' best interests at heart.

However, the research also uncovers persistent difficulties in conducting studies within this realm, necessitating ongoing critical dialogue both within the academic community and in wider societal contexts. Specifically, it underscores the importance of contemplating the policy ramifications for the use of digital self-care tools by individuals lacking in-depth knowledge of psychological methods. These tools are designed for home use without direct therapist intervention.

I also emphasise the need to involve different stakeholders in the HCDP, such as therapists and end-users. While the participant involvement in design holds promise (see Section 1.2.2), it also necessitates cautious engagement when laypeople are involved in designing potentially harmful content, especially when dealing with content that could evoke negative emotions, and that sharing would be an issue due to privacy concerns. Engaging in ongoing conversations with the research community and experts is vital for identifying responsible design strategies to address these challenges.

The diverse target group of this dissertation highlights the delicate balance required in user studies and design processes: 1) encouraging users to confront difficult emotions but without promoting rumination or re-traumatising experiences, as well as 2) providing supportive guidance without impeding autonomy or engagement in the process of self-care. Achieving this balance demands thoughtful ethical considerations.

I hope that my thesis provides initial guidelines on getting this balance right, providing beneficial features into VR applications for self-care that aim to offer everyday support for a broad range of people. I hope it inspires future work in carefully designing their technology for mental well-being, and considering opportunities and risks to an equal extent.

1.3 Terminology

To explore mental well-being in more detail, this thesis is interdisciplinary, in particular being situated at the intersection between psychology and HCI research, and mental health and well-being practice. As each field uses its own terms and concepts, there is a need to clarify the working definitions used in this thesis. An in-depth view and explanation of those concepts will be given later in Chapter 2. For easy reference, the working definitions of terms and concepts terms are presented in Table 1.2.

Throughout this thesis, the following terminology clarifications are important for understanding the nuances of writing.

- "VR" specifically denotes immersive virtual reality environments, excluding CAVE systems and similar technologies.
- The use of first-person singular pronouns "I/me" reflects my personal perspectives, opinions, and the findings unique to this dissertation. In contrast, "we/our" indicates contributions and viewpoints from the broader research team associated with the corresponding publications.
- "Paper" and "publication" are used interchangeably, referring to own publications labelled from A to F in this dissertation.
- "Thesis" and "dissertation" are employed interchangeably, referring to the content of this document.
- An "intervention" describes a technological experience designed to support self-care, mental health, and/or well-being. In contrast, "prototype" is used to refer to such interventions discussed in the papers, highlighting that it is a (virtual) artefact that is in the experimental stage. Meanwhile, "application" denotes any technological experience that is more developed, regardless of its focus on self-care.
- "Self-care activity" pertains to any particular action or exercise aimed at self-care, like a mindfulness exercise. "Self-care practice" encompasses the broader habit of engaging in self-care, potentially involving multiple activities.

Table 1.2: Working definitions of concepts and theories used in this thesis, inspired by related work as indicated. The field of origin is listed in brackets. Listed in alphabetical order.

Concept	**Working Definitions**
Autonomy	(developmental psychology) the capacity to make independent choices informed by personal principles and being self-governing [326, 547]
Cognitive Change	(cognitive psychology, mental health) modifying people's behaviour-related thoughts, feelings, goals (through changing perception or activating already existing perception) [192, 526], that result in a fundamental shift of self-perception or the perception of outside-situations [624]
Emotion	(cognitive psychology, affective science) encompass both short-lived physical reactions [150] triggered by specific events [180] and conscious sensations of emotions usually defined as *feelings* [150]. Emotions with low valence are categorised as *negative emotions*, but have valuable and positive functions [422].
Empowerment	(social psychology, mental health) 'giving control' and 'power-to' people [256, 499], including the subjective perception of being enabled for decision-making [476]
Engagement	(educational psychology) manifestation of intrinsic motivation [450]
Eudaimonia	(positive psychology) living a meaningful life, completing goals, developing skills, contributing to society, being challenged or feeling a sense of purpose; in summary, striving to reach one's full potential [254].
Hedonia	(positive psychology) experiences that we enjoy, that provide pleasure and happiness [254]
Hermeneutic Scaffolding	(psychology, philosophy, HCI) technology's design steers people's perception towards certain aspects of reality or themselves [595]
Internal states	(psychology) emotions, thoughts, motives and behaviours that are often unconscious [214, 442]

Introspection	(psychology) the examination of one's internal states [100]
Mental Health	(psychology, mental health) a positive goal that can be constantly improved, not a state of mind without illness [17], used in a clinical setting
Mental Well-being	(positive psychology) dynamic optimal state of psychosocial functioning, referring to recovering, maintaining and improving a state of psychological and emotional health that enables an individual to function effectively in society and meet the challenges of everyday life [98]
Mindfulness	(cognitive psychology, mental health) mental state of present-moment awareness (intentionally focusing on physical or internal states, *what* people focus on) and mental attitudes (curiosity, acceptance, self-compassion,*how* people engage with experiences) in the present moment with all senses, informed by contemporary psychology [272]
Multi-stability	(philosophy, HCI) difference between intended and practical use of technologies [596].
Pragmatic Scaffolding	(psychology, philosophy, HCI) praxis-oriented perspective through scripts in technology's design that encourage particular actions [595]
Rumination	(cognitive psychology) dwelling on negative thoughts and emotions, getting stuck in negative emotional thought cycles [213, 178]
Scaffolding	(developmental psychology) encouragement, guidance and support from the outside, extrinsic motivation [483], that support people in completing a task or learning skills [54]
Self-Awareness	result of various self-care acitivites, real-time in-the-moment understanding of oneself on a conscious level, recognising one's internal states at a specific moment [458]; used synonymously with situational self-awareness and self-focused attention [113]

Self-Care	(psychology, mental health) mainly intentional actions and practices to recover (reactive) and to maintain and improve (proactive) mental health and well-being [352, 655]; undertaken by laypeople on their own behalf [637]; is learnable [637].
Self-Care Technology	(HCI) a technology that is specifically designed to facilitate self-care practices [551], abbreviated to SCT
Self-Efficacy	(social cognitive psychology) confidence in one's ability to complete tasks, achieve goals and to overcome challenges to handle similar situations in the future in a better way [37]
Self-Expression	(developmental psychology, mental health) communicating internal states outwardly, including nonverbal cues like facial expressions, brief exclamations of awe or surprise, and verbalising emotions, e.g. naming emotions, journaling, visualising emotions [228]
Self-Knowledge	(cognitive + developmental psychology) a dynamic process accumulated over time with the aim to gain knowledge about the self, allowing a person to be aware of, understand, and recognise unconscious thoughts, emotions, motives, and behaviours on a deeper and more comprehensive level than self-awareness [214]
Self-Reflection	(cognitive psychology) inspection and evaluation of one's thoughts, feelings, and behaviour, clarity in understanding and evaluating internal states [221]
Techn. Intentionality	(philosophy, HCI) technology is designed with a certain intention in mind, amplifying certain aspects of reality while others are reduced [257]

1.4 Thesis Outline

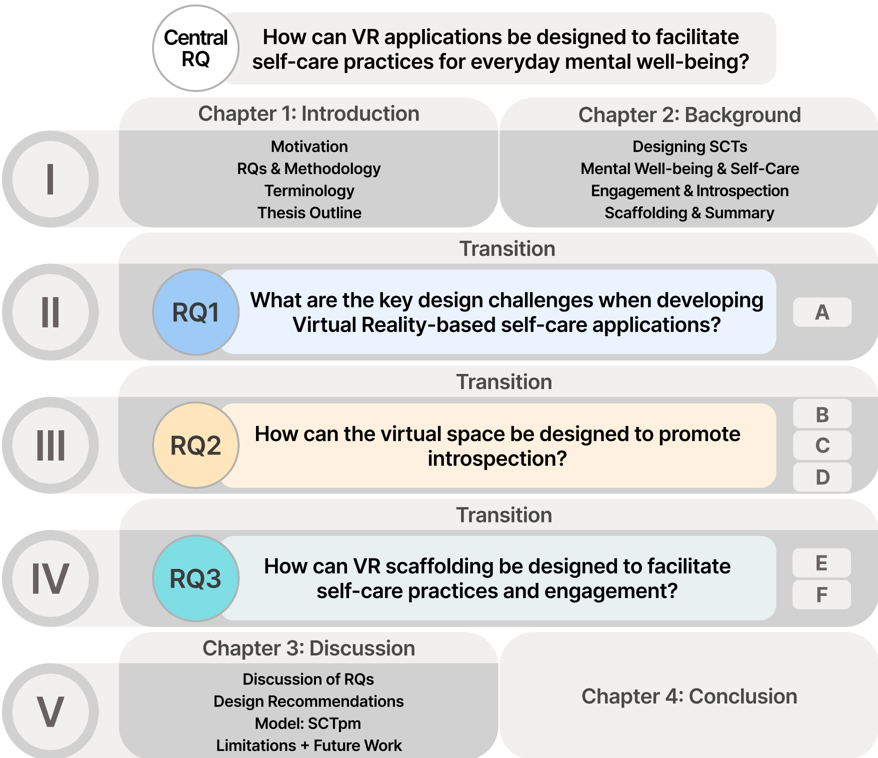

Figure 1.2: Thesis Outline: The thesis is structured into five parts with chapters and sections each, all contributing to the central research question. Part I encompasses two chapters, *Introduction* and *Background*, with several sections. Part II, III and IV each start with a *Transition*, and are dedicated to answering one specific research question each. Papers A-F are presented in these chapters accordingly. Part V encompasses two chapters, *Discussion* with several sections, and a *Conclusion*.

As visualised in Figure 1.2, this cumulative thesis is split into five parts. The first part, *Introduction & Background*, introduces and motivates this thesis. It consists of two chapters with several sub-sections.

The first chapter, *Introduction*, motivates the relevance of the whole thesis based on research gaps identified from societal needs and related HCI work. It is used to provide an overview of working definitions of key concepts used throughout the thesis, presents specific problem definitions and formulates three specific research questions (RQs) that are addressed in this dissertation. Further, it discusses the research methodology to address the RQs, defines the overall contribution of this thesis to the field of HCI, and provides a statement about the general ethical practice throughout the research. This chapter ends with providing a thesis outline.

Chapter two, *Background*, elaborates on relevant background & terminology that is needed to contextualise and understand this work, including definitions of the most important concepts that are employed throughout this thesis. Amongst others but not limited to, it presents current discourses of designing self-care technologies, defines mental well-being, and conceptualises self-care practices. It discusses how engagement and self-awareness are important concepts for self-care, and how to design SCTs in that regard. Then, possible outcomes of self-care practice are described, ending with defining methods to support the aforementioned processes for self-care. Throughout the whole chapter, relevant HCI literature and exemplary applications are presented that help to showcase applicability and distinguish this thesis from other works in the field.

Part II, III and IV of this thesis target one specific RQ each, with one or more of my publications contributing to answering this RQ. Each part begins with a short transition, which elaborates on how findings from previous research inform the design of prototypes that are presented in that part. Each publication is introduced, including its digital object identifier (DOI), linking the work to the official online version of each publisher. The papers are integrated into this thesis, including motivation, related work, design (if needed), evaluation and discussion specific to each paper.

Part V of this thesis consists of two chapters and presents a meta-discussion and the conclusion. In the chapter *Discussion*, the RQs are revisited and discussed. Based on the findings of this dissertation, five specific design implications are derived and discussed. Then, this thesis contributes theoretical knowledge in the form of a process model, which provides specific design ideas that can support VR designers in designing effective and safe self-care applications. Afterwards, this chapter critically reflects on VR-based SCT, including the limitations of this dissertation and general barriers hindering public adoption that need to be overcome. It ends with discussing questions that remain unanswered at the point of completion of this thesis, reflecting on possible future research.

This thesis ends with a *Conclusion*. It summarises the key findings of this dissertation.

2 Background

The field of self-care is vast and complex, resisting simple definitions and distinct boundaries among psychological concepts which often interrelate. This complexity extends to HCI, where the application of these concepts in technology design also highlights their interconnected nature. Consequently, this chapter aims to provide a profound overview of core concepts relevant to this thesis, exploring how their theoretical understanding influences HCI frameworks and guidelines, which in turn guide the development of the self-care prototypes presented in this dissertation.

In this chapter, working definitions are explicitly marked. At the end of each section, connections to how this dissertation utilises the concepts, theories, and frameworks are emphasised. An overview is provided in Table 2.1. This chapter includes only a select few prototypes from related work to demonstrate how HCI research has integrated theoretical psychological concepts and to highlight design choices that have inspired this dissertation. For a more detailed review of the related work that informs the specific papers, please refer to the related work sections of the relevant publications.

This chapter begins with delving into ethical and moral considerations when designing technologies, in particular when designing SCTs and virtual environments. Next, it defines umbrella terms such as mental well-being and self-care, then defines core concepts relevant to creating engaging experiences. Afterwards, it provides insights into selected self-care activities, such as exercises for mindfulness, self-reflection and self-expression. Then, this chapter discusses potential outcomes when engaging with self-care activities, such as gaining self-awareness, cognitive clarity and change. It ends with exploring the concept of scaffolding that can guide users through self-care activities, thus rendering them more effective.

Table 2.1: Psychological concepts, theories and practices that papers address, and that prototypes of this dissertation are specifically designed for. The two main concepts are highlighted. Please note that the papers' findings can show links to other concepts, which are not depicted in this table.

Psychological Concepts	**Paper**
Mental Well-being	A, B, C, D, E, F
Self-Care	A, B, C, D, E, F
Autonomy	D, E, F
Cognitive Restructuring	E, F
Competence	B, D, E
Empowerment	B, D, E, F
Engagement	B, C, D, E, F
Mindfulness	B
Scaffolding	E, F
Self-Awareness	B, C, D
Self-Efficacy	E
Self-Expression	D, E, F
Self-Knowledge	E, F
Self-Reflection	C, E, F

2.1 Designing Self-Care-Technologies

> *"Good design is actually a lot harder to notice than poor design, in part because good designs fit our needs so well that the design is invisible."*
> – Don Normann (pioneer in designing technology)

Good design must cater to user needs, support intuitive interactions, convey clear meanings, and provide immediate feedback to communicate the outcomes of user actions [402]. Further, it should empower and promote well-being while being engaging and ethically safe to use [390]. Yet, the challenge is to determine specific factors that render design 'good' in the aforementioned ways.

Encouraged by this challenge, this thesis, being at the crossroads of HCI, VR design, and psychology, has carefully considered design decisions regarding the VR prototypes for self-care. To provide background on design principles that inform this dissertation, this chapter first delves into ethical and philosophical considerations in regard to designing interactive technologies. Afterwards, it elaborates on specifics when designing technologies with the aim to promote self-care. Finally, it presents core concepts relevant when specifically designing VR experiences, in particular when creating VR experiences for self-care.

2.1.1 Designing Interactive Technologies

Engaging in self-care is deeply personal and can make users feel vulnerable, especially when reflecting on negative emotions or situations. Therefore, it is essential that technologies such as VR, examined in this dissertation, are designed ethically and morally to support self-care without causing harm. This involves making the users as comfortable as possible with the technology's design, to create 'good' design, to maximise the effectiveness and safety of self-care activities. Thus, this section addresses the ethical and philosophical considerations in designing interactive technologies that inform the prototypes developed in this dissertation.

Technologies have the power to influence users' perceptions of the world, their experiences within the world, and their actions and behaviours [595, 596]. In that regard, technologies can be designed: (i) to function (that is a prerequisite that will not be delved into more detail here), (ii) to scaffold a hermeneutic or experience-oriented perspective, and (iii) to scaffold a pragmatic or practice-oriented perspective. Prototypes of this dissertation aim to leverage the last two concepts, as they aim to influence what users are aware of as well as their self-care behaviours. Hence, hermeneutic and pragmatic scaffolding will be explained in more detail. Part IV of this thesis specifically explores different means of how VR applications can scaffold both perception and self-care behaviours.

How Technologies Mediate Perception.

> The hermeneutic phenomenology describes how technologies can steer people's perceptions towards certain aspects of reality or themselves [596].

To elaborate, the function of technologies can help to shape what people perceive as 'real'. For example, without technology, a tree is usually perceived as having a brown trunk with green leaves. Looking at this tree with an infrared camera, most aforementioned aspects, such as leaves and colours, get lost in people's perception. Instead, the thermal imaging reveals the tree's health status. Heat dissipation for healthy trees is relatively even due to a smooth water distribution while a diseased tree will show disruptions of heat with cooler areas being apparent in the image [436]. Steering the focus towards certain aspects could be leveraged for facilitating an inward focus and ameliorate an understanding of internal states, such as needed for many self-care practices.

How Technologies Mediate Actions. Technologies can also be imprinted with certain 'scripts' that nudge users to act in a specific way.

> Pragmatic scaffolding describes that technology encourages or discourages certain actions or behaviours [596].

For example, speed bumps motivate car drivers to reduce their speed. A thermometer would do both, shape the perception of what is considered a cold or warm temperature (hermeneutic scaffolding) and prompts a certain behaviour, for example, to take a jacket (pragmatic scaffolding). Leveraging these "scripts", technology could provide a framework that - even unconsciously - nudges users to adhere to certain strategies for well-being and self-care behaviours.

Balancing Potential and Risks. Hermeneutic and pragmatic scaffolding demonstrate that technologies are not neutral.

> Instead, the term *intentionality* describes that technologies are always designed with a certain intention and purpose in mind, amplifying certain aspects of reality while others are reduced [257].

Thereby,

> the original intentions behind a technology's design can often differ from its practical use, termed the *multistability* of technologies [596].

Infrared cameras, for example, were originally developed for military purposes, not to discern if trees are healthy or not [436].

Given the significant influence of technology on people, designers bear the responsibility to create ethical and morally sound technology [595]. Further, design inherently reflects the designer's expertise, cultural background, and societal norms, making informed decisions even more crucial [551]. Although the multistability of technologies counteracts their intentionality to an extent, designers should strive to foresee potential contexts and uses, including those that could be harmful [596]. It is critical for designers to make well-informed predictions about how the ethical implications of their technologies, fostering positive outcomes, and how to minimise the potential for harmful usage.

To address this challenge, many designers adopt a HCDP [4, 96], centering the design process around user needs. This dissertation employs two specific HCDP methods for prototype development. First, designers use imaginative strategies such as user stories, personas, brainstorming, focus groups, or workshops to anticipate different requirements, most likely context of use, and potential unintended use cases [595]. Secondly, a Constructive Technology Assessment (CTA) allows designers to analyse and enhance existing designs or related works. Both methods can engage relevant stakeholders, such as therapists and non-expert users in the case of this dissertation. Involving all personnel can further reinforce the idea that technology facilitates rather than dictates user actions, thereby supporting complex tasks like emotion management in self-care without oppressing autonomy. This approach helps counter the fear of technology technocracy, and underscores technology's role as a supportive tool.

No matter the chosen method for informed design decisions, people taking part in the design process of technologies need active encouragement to think about all possible use cases and mediations from technology [596]. Potentials and pitfalls need to be carefully balanced when designing technology. Yet, Rogers [472] underscores the importance of not being overly cautious; instead, technologies should also be designed to be exciting, engaging, and provocative, stimulating both learning and reflection. She emphasises the potential of unconventional design that could move technologies from the background to the foreground, creating a vision of technologies as part of our everyday lives.

Potential to support self-care goals and risks of unintended harmful design were carefully considered for each prototype before evaluation with users. All prototypes aim to steer the focus on a specific self-care objective, thereby applying hermeneutic scaffolding. Moreover, prototypes of *E - SelVReflect* and *F - MoodShaper* additionally prompt certain actions, thus applying pragmatic scaffolding. All design decision were based on informed decisions due to in-depth literature reviews, CTAs and included iterative design cycles with stakeholders, especially therapists and users. All of them chose explorative approaches and imaginative methods due to lack of comparable systems. Additionally, augmentation was used for prototypes presented in papers *E - SelVReflect* and *F - MoodShaper*, relying on a similar method previously tested in *D - MoodWorlds*. This dissertation extends ideas of Verbeek [595] by exploring software applications in regard to VR rather than tangible tools.

2.1.2 Designing for Self-Care

Designing technologies which specifically target self-care practice presents unique challenges [491]. Technology design, with its own ethical and moral boundaries, is intertwined with complex and personal topics such as mental health and self-care [491]. As these topics are inherently personal and can render people vulnerable, it becomes even more relevant to design technologies that are aimed to support self-care objectives in an ethical and moral way. In particular, the reflections of designers' values and beliefs in the technology's design can potentially have larger repercussions when users become vulnerable [551]. Additionally, people have such varied needs, backgrounds, and situations that a one-fits-all SCT seems neither practical nor effective [86]. Thus, for SCTs to truly serve as meaningful companions in mental health, it is imperative that they are researched, designed, and evaluated from multiple perspectives and methodologies [86].

A critical concern inherent to SCT development is the potential to oversimplify mental distress and health while overstating the promised effectiveness of the technology or application [551]. For example, Parker et al. [421] examined advertisements for 61 mobile mental health applications and discovered that they commonly depicted mental health issues as ubiquitous while presenting the applications as universal remedies. This highlights the importance of ethical design practices, rigorous preliminary research, and meticulous design considerations. It is essential to avoid overstating results when evaluating prototypes, especially given the sensitive nature of self-care practice.

2.1.3 Designing Virtual Realities

Designing technologies, particularly SCTs, is inherently complex. Integrating VR adds further challenges. For instance, additional extensive knowledge in fields such as tracking technologies, multimodal interaction, and computer graphics is required when designing VR applications [286]. However, VR offers unique potential for self-care that extends beyond those of traditional desktop and mobile technologies, as will be elaborated on in this section. Despite the intricate development process and the need to balance multiple objectives, VR offers unique potential to promote self-care that extends beyond those of traditional mobile and wearable SCTs. This potential of VR as SCT will be highlighted in this section, along with defining VR, immersion and presence, and providing insights into fields of application in regard to mental health and well-being.

Defining VR. Virtual Reality (VR) originates from the Latin term '*virtualis*', meaning 'being such in essence or effect, although not formally or actually', combined with '*reality*', referring to human experiences. Taken together, these terms suggest that VR is a simulation that closely mirrors or augments people's perception of reality. This is achieved through a powerful graphics processing unit and wearing head-mounted displays that together create three-dimensional computer-generated worlds that stimulate human senses such as vision, hearing, and touch. This complete immersion in a synthetic environment positions VR opposite of reality at the far end of the Reality-Virtuality continuum, with augmented reality and other mixed realities situated in between [367]. This notion influenced the working definition of VR based on Milgram et al. [368]:

> "The commonly held view of a VR environment is one in which the participant-observer is totally immersed in a completely synthetic world, which may or may not mimic the properties and physical laws of a real-world environment" [368].

This definition prompts a debate on VR's realism. Sutherland, an early VR pioneer, envisioned VR to be so realistic that a virtual bullet could be fatal [567]. However, he also recognised the technical and ethical challenges inherent in replicating reality so closely. Contemporary views suggest that VR will neither be able to nor should attempt to perfectly replicate reality [531]. Instead, it should be positioned within rather than at the extreme end of the Reality-Virtuality Continuum [531].

Further, recent perspectives on VR adopt a more human-centric approach, focusing on the interactions between humans and the virtual world (e.g. [95, 236]), as well as the impact of these virtual environments on users (e.g. [531, 600]).

Interaction in VR involves user communication with the system via controllers, gestures, or eye movements, facilitating both input and output [264]. The degree to which these interactions correspond to interactions from the real world is called interaction fidelity [359]. While higher fidelity can enhance intuitive and natural use, lower fidelity may improve performance and enjoyment while reducing fatigue [264]. As users can perceive the artificial stimulus as real, a lack of tactile feedback for visible objects can lead to accidents, discomfort, and confusion [264]. Thus, addressing this visual-haptic conflict is an ongoing challenge regarding VR interaction.

Some researchers particularly highlight VR's lasting impact on users, also beyond the actual experience, emphasising the significant "emotional experience" it provides [600]. The emotional impact that VR can have becomes important in regard to self-care and mental well-being, as emotional health is an important aspect of both. I refer to Section 2.2 for further reference.

Immersion & Presence. Creating these emotional experiences benefits greatly from immersion and presence. Immersion refers to the objective level to which a virtual system is technically able to stimulate users' perception of sensory, vestibular, proprioceptive, and interoceptive channels to create the illusion of a coherent virtual environment [71, 466]. This exemplary includes the resolution, weight and fit of the head-mounted display or the performance of soft- and hardware components [264].

However, the stimuli presented by the devices are always interpreted by a user, and as such, immersion can guide towards an engaging experience but cannot guarantee it [264]. Instead, the better a system's immersion the greater the *potential* for a user to forget reality for that moment [466]. In other words, as Oculus (company developing VR hard- and software) co-founder Palmer Luckey puts it: "the goal of VR is to make people feel as though they are in a place they are not". As such, presence is defined as:

> Presence is a subjectively perceived inner psychological state, reflecting the perception of 'being-there' within the virtual environment, regardless of the contrast to the real, physical environment [264].

High presence allows users to interact with the virtual world in a way that feels interactive and immersive, transcending the mere act of pressing buttons and observing outcomes. What is described here can relate to the concept of flow, in which users are fully absorbed in a VR experience, characterised by a sense of effortlessness, loss of self-consciousness and loss of sense of time, which seems to either slows down or speeds up [383, 515]. With that, flow can represent an experiential approach to positive psychology [383], resulting in positive emotions [142] and can positively influence the intention of continued use of VR applciations [244]. Additionally, presence positively correlates with many concepts relevant to this dissertation, for instance with mindfulness [389, 513], agency [267], emotions [267] and general user experience [504, 571]. However, high presence and flow might also lead to a diminished awareness of one's physical surroundings, self, and body [428], which could limit opportunities to pause, reflect, and learning [266], which are crucial components of self-care. While designing for high presence is a common objective in HCI, this dissertation delves deeper into how presence influences self-care outcomes.

VR as SCT. Since the invention of the first head-mounted display in the 1960s, VR has significantly impacted the medical sector. By the 1990s, it was being utilised for medical training, procedure planning, diagnostics, and treatment in various fields including dentistry, surgery, and mental health care [241, 431]. Notably, VR has been famous for its application in exposure therapy, helping patients confront phobias in controlled virtual settings to regulate emotions [475]. Its capabilities for creating controlled, realistic environments make it valuable for diagnosing, treating, strategy-practising [431], and measuring outcomes [351] across various medical fields including dentistry, surgery, mental health and well-being care [431].

With advancements in affordable VR hardware around 2013, the technology gained commercial viability, sparking interest beyond clinical applications to broader mental well-being uses. A review from 2021 highlights VR's potential to enhance social connectivity, manage loneliness, and improve mood, emphasising its growing use for stress management and relaxation as well [21, 432]. Despite these advancements, VR is still predominantly associated with medical training and exposure therapy, with limited research exploring its utility in less clinical well-being applications (except the well-researched field of stress reduction [601]) such as self-reflection [46] and self-expression [290]. Both, VR's application for clinical mental health and well-being support, are overshadowed in public discourse by its purpose for gaming [62, 557]. This dissertation contributes to current research by exploring VR as a meaningful self-care tool, aiming to shift public and academic perspectives towards its benefits for personal well-being.

Effectiveness of VR. HCI research continues to explore whether self-care activities in VR can lead to comparable, if not even better, results compared to traditional methods. To that end, Ma et al. [338] found that VR can be more effective in facilitating mindfulness practice than traditional methods by reducing external distractions and using unique visual aids for tasks like breathing exercises. This has been corroborated by findings indicating a correlation between presence in VR and increased mindfulness [389, 513]. Moreover, experts in mindfulness practice recognised VR's potential in focusing users on themselves and the present moment [389], which was found especially helpful for beginners [333]. This informs using mindfulness-based self-care activities for self-awareness, as done in paper *B - Haptics*.

Further, VR has proven to enhance reflection and empathy in teaching contexts through teachers embodying students, thus deepening mutual understanding compared to real-life classroom settings [555, 304]. Additionally, being immersed in VR was found to influence which information were processed and increased empathy towards those involved in the Afghanistan conflict more effectively than traditional methods [284]. VR has also been found to be more effective in facilitating experiential learning and reflection [304]. Additionally, VR significantly improves internal motivation and training psychology in regard to learning and practising skills relevant to sports [651]. The fact that VR can better facilitate reflection and experiential learning is important for papers *C - VeatherReflect*, *E - SelVReflect* and *F - MoodShaper*.

Additionally, VR's capacity to evoke emotional states and responses similar to reality is significant for this dissertation, as this makes VR an effective tool for mood induction, emotion regulation and inducing positive affect. In exploring VR as a mood induction procedure (MIP), studies have demonstrated its efficacy in inducing specific emotional states such as anxiety, benefiting exposure therapy applications [365], and stress, which helps users practice coping strategies [582]. Furthermore, VR has been shown to elicit a range of negative emotions, facilitating the learning of emotion regulation techniques [373]. Montana et al.'s review [373] of 414 HCI applications demonstrated VR's effectiveness in improving emotion regulation and well-being. Similarly, another review [602] encompasses 10 years of HCI research until 2021, emphasising its role in improving emotional awareness and regulation skills. Moreover, it was shown through linking virtual environments with neurofeedback that VR can activate brain areas associated with specific emotions [331], which can be used to tailor virtual environments to elicit specific desired emotions.

Given VR's ability to elicit real-life responses, research has also explored which specific virtual elements contribute to VR's effectiveness in inducing emotions. Research indicates that ambient colours [331], music, weather, season, background noise [190] and lighting [38] in virtual environments can influence emotions. However, it remains unclear which elements are most impactful. Notably, individual differences affect how audiovisual stimuli are perceived, suggesting a need for personalised virtual environments to effectively induce specific emotions [433]. Overall, the consensus in HCI research confirms that VR can be a powerful tool to elicit complex emotions [364].

> VR's proven effectiveness compared to traditional methods in regard to mindfulness exercises, learning, reflection, empathy, self-awareness and emotion elicitation underscores its potential for self-care practice. This motivates this dissertation and all papers within to explore the design space of VR-based SCT in more depth, focusing on its capacity to support autonomous well-being.

2.2 Mental Health vs. Mental Well-being

> *"There is no health without mental health; mental health is too important to be left to the professionals alone, and mental health is everyone's business."* – Vikram Patel (psychiatrist and awarded researcher for global mental health)

The previous section highlighted that public discourse and HCI research primarily focus on VR development for mental health. In contrast, the main aim of the prototypes of this dissertation is to promote mental well-being. The following section will clarify the distinction between both concepts, and define emotions as a core term of well-being and used in many of my papers in more depth.

Health is categorised into three interconnected areas: physical (related to the body), social (pertaining to relationships and social networks), and mental health (concerning our mind, feelings, and behaviour). All three correlate with each other. For instance, improved mental health can reduce cigarette usage, thereby enhancing physical health [409]. Additionally, having a walk in nature not only benefits physical and social health but also enhances mental well-being [227]. Conversely, stress, a mental health issue, also causes physical changes such as increased heart rate and decreased skin temperature [636].

Before the 1940s, mental health was considered as a spectrum of symptoms beyond individual control, with mental disorders at one end and optimal mental health at the other [57, 282]. This perspective was challenged by humanistic psychology. They emphasised the uniqueness of individual experiences [520, 116], focusing on continuous personal and collective growth. It also emphasises the importance of navigating through mental health issues that might hinder this growth as well as proactively maintaining and improving mental health [520]. Still, the term mental health is used to describe mental health disorders in the clinical context [17]. To define mental health, this dissertation follows notions from humanistic psychology:

> Mental health is defined as 'human flourishing' - a positive goal that can be constantly improved rather than a state of the mind without illness; this term highlights the clinical aspects of mental health, such as seeking therapeutic support for mental health disorders [17].

In contrast, mental well-being is a term that highlights proactive engagement in activities aimed at 'human flourishing' within daily life. It emphasises practices that promote overall happiness and fulfilment, such as hobbies or walks in nature, designed to enhance one's quality of life and personal growth [17]. It should be noted that the view of mental well-being can differ. For instance, some scholars define mental well-being as part of mental health (e.g. [282]), while the World Health Organisation (WHO) considers it the outcome of mental health [638]. To simplify, this dissertation follows the subsequent working definition:

> Mental well-being is an abstract construct best described as *"a dynamic optimal state of psychosocial functioning"* [98]. It refers to recovering, maintaining and improving a state of psychological and emotional health that enables an individual to function effectively in society and meet the challenges of everyday life.

Depending on the definition used, mental well-being is divided into three [282], five [514], or six [485] distinct sub-domains, including, for example, emotions, autonomy, personal growth or self-acceptance that are all relevant to this dissertation. However, to simplify matters, this dissertation follows mental well-being components as described by Huta [254]. It consists of hedonic and eudaimonic elements, which are defined as outlined below:

> *Hedonia* refers to experiences that people enjoy, that provide pleasure and happiness. This can include entertainment, hobbies and relaxation. *Eudaimonia* refers to the subjective notion of living a meaningful life, completing goals, developing skills, contributing to society, being challenged or feeling a sense of purpose; in summary, striving to reach one's full potential [254].

Desmet et al. [156] further specify that technologies designed with a hedonic focus aim to evoke positive emotions, while those with a eudaimonic orientation promote self-actualising experiences, as seen in serious games or VR therapy. Hedonic and eudaimonic well-being, along with frameworks like Seligman's PERMA theory [514], consider positive emotions essential. Given the significance of emotions for well-beig, and in this research, the next section will delve into the complexities of emotions.

Emotions, Feelings, Mood and Affect. These terms are often used interchangeably in daily conversation, though they hold distinct theoretical meanings. Affect describes the broader, fundamental sense of something being positive or negative [491]. Moods are emotional states that can persist for extended periods, and can be affected by factors like weather or interpersonal relationships [260]. Feelings is a term used to describe being consciously aware of emotions and often blends multiple emotional states [150]. Emotions themselves are intense but brief bioregulatory responses that last about six seconds and are typically triggered by specific events [150]. These emotion-triggering events may evoke several interconnected emotions, for instance happiness, excitement, satisfaction and awe [137].

Despite this clarity, many find it difficult to identify and name specific emotions, and using varied terminology might complicate communication unnecessarily [259]. For simplicity reasons, this dissertation will use the term 'emotion' according to the following working definition:

> Emotions encompass both short-lived physical reactions [150] triggered by specific events [180] and conscious sensations of emotions usually defined as *feelings* [150].

The research done in this dissertation explores positive and negative emotions. While some researchers list emotions statically, depending on the research distinctly identifying six [181] or up to 27 [137] emotions, the positive-negative continuum implies categorising them on dimensions. As done in the Circumplex Model of Affect [438], emotions are classified in regard to their valence (pleasure to displeasure), describing the attractiveness of an event, and arousal (high to low), referring to the level of being physiologically and psychologically stimulated and alerted by them [438]. Following this notion, low-valence emotions such as sadness or anger are colloquially referred to as 'negative' emotions. However, critics argue against the simplistic polarity of emotions suggested by models like the Circumplex Model of Affect, which associates 'negative' emotions with negative outcomes [322]. Instead, they provide valuable information [507], help coping with potential danger [183] and motivate personal growth [242] Consequently, when this dissertation uses the term 'negative' emotions, it aligns with the following definition:

> Adopting the dimensional approach [438], low-valence emotions are called *negative emotions*. However, this does not imply a negative outcome; rather, it recognises the valuable and positive functions of negative emotions [422].

This thesis aims to enhance mental well-being through everyday practices, focusing on fostering 'human flourishing'. Papers *B - Haptics* and *D - MoodWorlds* mainly provide a hedonic experience focusing on providing pleasure and relaxation, and papers *C - VeatherReflect*, *E - SelVReflect* and *F - MoodShaper* mainly strive to provide eudaimonic well-being through promoting self-growth through practising self-care skills such as self-reflection and emotion regulation.

2.3 Conceptualising Self-Care: Activities for Various Self-Care Goals

"Self-care is not a one-time deal. It's the constant repetition of many tiny habits, which together soothe you and make sure you're at your optimum—emotionally, physically, and mentally." – Brianna Wiest (author)

Mental well-being can be improved significantly when practising self-care. Self-care practice refers to the habit or routine of regularly incorporating behaviours or strategies promoting mental well-being into everyday life [99]. Effectively, self-care practice can encompass a combination of lifestyle choices and self-care activities, that are consistently applied in daily life [655]. This dissertation investigates the design of VR-based self-care activities. Thus, this section begins by defining self-care and discusses its connection to empowerment. It then presents the primary self-care activities — mindfulness, self-reflection and self-expression — that shape the prototypes developed in this thesis, explaining their selection based on their potential benefits and related research gaps.

Defining Self-Care. Self-care is a concept with over 136 definitions depending on different research lenses, and perspectives, which highlights a lack of consensus among professionals, researchers, and the public [218]. Martinez et al. [352] defines it as follows: "*the ability to care for oneself through awareness, self-control, and self-reliance in order to achieve, maintain, or promote optimal health and well-being*" [352]. However, given the central role of self-care in this dissertation, it is essential to examine this concept in a more nuanced way.

In this thesis, self-care is conceptualised as both a self-referential and self-relational practice [551]. Drawing from social behaviourism, the 'self' can be understood both through interactions with others and observing other people's behaviour (interpersonal perspective) [44], and through introspective evaluation of conscious and unconscious aspects of oneself (intrapersonal perspective) [26]. The WHO [637] outlines the involved parties and their role in self-care further: "*[self-care activities] are undertaken by laypeople on their own behalf, either separately or in participative collaboration with professionals.*". This thesis adopts this notion, focusing on providing self-care activities for laypeople or novices who are not assisted by professionals.

The act of "care", of looking after oneself, encompasses both physical practices, such as exercise, nutrition or brushing one's teeth [215, 197], and "techniques of the self", which is the focus of this dissertation. A key aspect of techniques of the self is becoming aware of internal states [442]. These techniques involve becoming aware of and expressing emotions, strengthening relationships, as well as being mindful of taking breaks and engaging in hobbies. Additionally, they include setting clear boundaries and effectively managing time to prevent feeling stressed and overwhelmed [655]. Inspired by all of these different definitions, this thesis follows this working definition of self-care:

> Self-care is mainly intentional actions and practices [655] that have the aim to achieve, maintain, or promote optimal health and well-being [352]. It is undertaken by laypeople on their own behalf [637].

These intentional actions can be both automatic daily practices that most people unconsciously undertake, such as eating and sleeping, as well as more intentional activities such as relaxation or practising mindfulness. If consciously undertaken, they are called *self-care activities*. All prototypes presented in this dissertation provide self-care activities. The WHO specifies: "*These activities for self-care are derived from knowledge and skills from the pool of both professional and lay experience*" [637] (own emphasis). The WHO hereby emphasises that self-care activities have to stem from knowledge or skills, which do not necessarily need to be taught by experts in clinical contexts but can also be learned without expert assistance. The latter is essential in the context of this dissertation, as SCTs can support skill development through eudaimonic and guided experiences, as explored in more depth in regard to VR-based self-care activities in this dissertation.

In theory, both automatic daily practices (such as eating) and intentional self-care activities (such as mindfulness exercises) can be categorised into reactive and proactive self-care activities, as defined below:

> *Reactive* self-care describes treating and overcoming unpleasant symptoms of mental illness, for example consciously seeking out relaxation when feeling close to a burnout [655]. *Proactive* self-care describes engaging with maintaining and improving one's health through health behaviour and health-enhancing activities such as daily habits that are aimed to improve an already healthy state of well-being [13].

This dissertation primarily explores proactive self-care activities, although they can also serve reactive purposes. Health behaviour, as mentioned in the definition of proactive self-care, includes preventive actions and engaging in health-enhancing activities while also avoiding risk behaviours like drunk driving or smoking [655]. However, in practice, these distinctions often blur, as individuals typically engage in proactive health maintenance and improvement while simultaneously managing minor symptoms of mental distress reactively [655].

The Self-Care Matrix. To conceptualise reactive and proactive self-care activities, El-Osta et al. [182] developed the Self-Care Matrix (SCM). Their framework organises self-care into four key dimensions (Activities, Behaviours, Context, and Environment). The SCM illustrates how various elements of self-care interconnect across micro, meso and macro levels. This thesis mainly focused on a person-centred micro and meso perspective on self-care, as highlighted in Figure 2.1 and explained in the following.

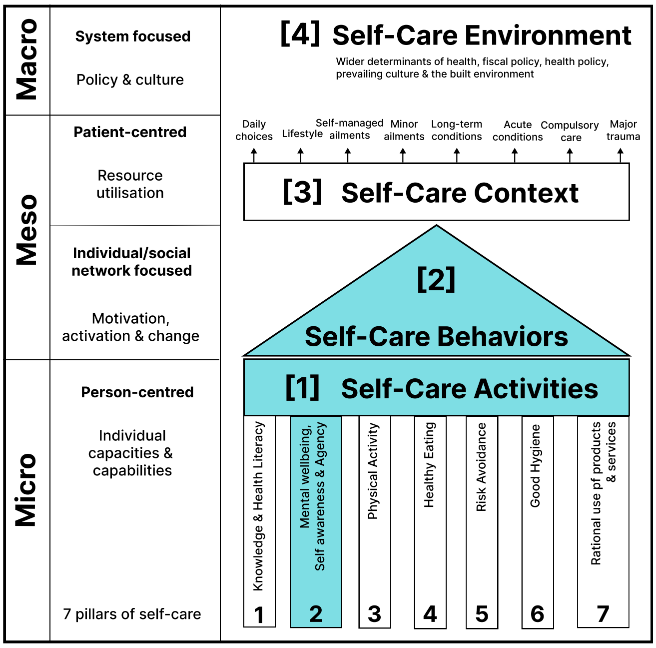

Figure 2.1: Adapted from The Self-Care Matrix from El-Osta et al. [182]. This thesis explores the design space of self-care activities [1], mainly in regard to pillar “Mental well-being, Self-awareness & Agency”, as well as means for motivation, activation and change in regard to self-care behaviours [2], highlighted in colour.

The first dimension of the SCM, *self-care activities*, takes a person-centred approach, focusing on interventions that enhance personal skills which benefit the integration of self-care behaviours into daily routine [182]. These activities are organised into seven pillars, such as improving health knowledge, enhancing mental well-being and self-awareness, promoting physical activity, and teaching risk avoidance strategies. VR-based self-care activities presented in this dissertation mainly focus on providing mental well-being, self-awareness and agency.

The second dimension, *self-care behaviours*, operates on a meso level targeting both individual and group self-care practices [182]. It emphasises that self-care has to be motivating and engaging, for example through providing nudges through people or technology - called scaffolding in this dissertation. This thesis further explores how VR-based SCTs can support motivation by addressing psychological needs, such as autonomy [483]. For a detailed discussion, I refer to Section 2.4.2. Further, the second dimension integrates behaviour change theory to encourage the adoption of positive lifestyle choices and routine self-care activities [151, 483]. Being motivated can lead individuals to incorporate self-care activities into their daily routines, which can help to foster cognitive and behavioural change [151], connecting the second dimension of the SCM with behaviour change theory [151, 483].

Dimensions three and four, *context* and *environment*, provide a broader view from a patient-centred perspective with a medical focus, considering external resources, clinical services, policy, culture and the respective public health landscape. While important, these dimensions are not specifically targeted by this thesis.

> This thesis explores self-care activities that support everyday well-being and supports with common life challenges. Paper *A - Haptics* presents a systematic review of VR self-care applications in the consumer market. Papers *B - Haptics* through *F - MoodShaper* showcase prototypes of VR-based self-care activities designed to motivate users and promote cognitive change, potentially leading to integrating self-care behaviours into everyday routines.

Self-Care and Empowerment. Empowerment plays a pivotal role in self-care, acting both as a driver and an outcome of self-care activities. For instance, feeling empowered can motivate and engage people to conduct self-care activities; well-designed self-care activities can promote the feeling of empowerment, and having experienced the positive outcome of self-care activities, such as increased awareness of internal states, can, in turn, empower and engage people, creating a reinforcing cycle.

Empowerment is broadly defined across various papers as the act of "giving individuals control over their own lives" [415] (for an overview see Ibrahim et al. [256] and Schneider et al. [499]). This notion emphasises the external act of "giving power to´´ people who can then independently act [344]. Other definitions underscore the importance of the subjective perception of being capable and entitled to act [476]. Accordingly, this thesis adopts the view of empowerment reflecting both the action of empowering and the resulting state of feeling empowered, as outlined below:

> Empowerment is the notion of giving power and control over one's life and decisions to the individual [499], as well as the subjective perception of having this control [476].

Empowerment is a critical factor for attaining mastery over one's life [447], influencing the ability to exert control over one's own circumstances, and fostering a sense of agency [385, 345] and self-determination (as explained in more depth in Section 2.4.2).

The concept of 'agency' has already been highlighted as a key goal in self-care activities within the SCM [182] and serves as a central design principle for all prototypes developed in this dissertation. Agency, which is intrinsically valued and subjectively assessed[517], plays a crucial role in effective goal-setting and taking action [274, 518]. This underscores the potential for technology designers to design for agency and empowerment intentionally. As this thesis focuses on VR, it follows notions by Smolentsev et al. [543] to frame agency in regard to virtual environments:

> Agency can be defined as the perceived ability to interact with elements of a virtual environment [543].

Agency is addressed in regard to different aspects in HCI research, relating to eight themes [499]. Of those, three are specifically targeted by prototypes of this dissertation: (i) they aim to provide mastery experiences that make users feel successful and competent with competency being a psychological need that, when met, can increase engagement [483]; (ii) to promote skill development, realised through scaffolding elements and qualitative visualisations, and (iii) empowerment through the design process, which I addressed by including stakeholders in the design and testing phases of all prototypes.

Some examples of HCI research that specifically mention designing for empowerment include co-creation sessions of virtual environments with people with dementia, with the aim of improving emotional well-being and empowering them to express their emotions [120]. Further, Khatibi [283] found that being empowered to engage with virtual objects related to war can inspire empathy, and Riva et al. [464] listed the benefits of being empowered in VR for treating various mental health disorders.

In this thesis, all prototypes provide agency by being able to interact with virtual elements (except *C - VeatherReflect* where agency was provided by allowing people to interact with their health data in a different way). They aim to provide mastery experiences by specifically addressing users' competence and promoting skill development in several areas of self-care.

2.3.1 Mindfulness

One of the most well-researched self-care activities - thus also being one subject of analysis in this dissertation - is mindfulness practice [601]. Mindfulness practice contributes to self-awareness by shifting the focus to oneself, current emotions and thoughts at that specific moment, and is thus also considered an experiential self-awareness activity that results in a mindful state [91]. The understanding of mindfulness varies, partly due to its long history [121, 333, 149].

> This dissertation follows a definition rooted in contemporary psychology, in which mindfulness is defined as a mental state of present-moment awareness, thus intentionally focusing on present-time aspects [272].

Following this definition, mindfulness encompasses two components: present-moment awareness, i.e. paying attention to specific physical or bodily objects and/or mental states in the present moment (i.e. *what* experience a person focuses on), and mental attitudes, e.g. curiosity, perceptual sensitivity to stimuli, acceptance of present moment experiences (i.e. *how* a person engages with experiences) [65, 324, 479]. Moreover, mindfulness also teaches awareness of the surrounding environment at that specific moment, thus overall, it describes a focus on the present moment with all senses [458]. A prominent example of a mindful experience is eating a raisin [458]. If done in a mindful way, one would savour every moment, feeling the haptic texture of each groove, listening to the crunching sound when biting into it, and savouring the sweet taste, without being distracted by the next to-do on the agenda. Importantly, children are more akin to being mindful, but we seem to lose more and more of this skill when growing up, which is why actively cultivating awareness and attention has to be practised and often re-learned [126, 357]. Notably, mindfulness is closely associated with self-compassion, which promotes a kind, accepting, and non-judgmental attitude toward one's emotions and thoughts uncovered through mindfulness practices [27, 91]. Instead of avoiding painful emotions or failures, they should be met with kindness and self-compassion [186], which, among others, can strengthen oneself against mental health issues such as burnout [601].

Benefits of Mindfulness. Mindfulness exercises can serve as self-care activities, as they are associated with decreased stress and anxiety [523]. The most established mindfulness program is known under the term mindfulness-based stress reduction (MBSR) [601]. Research has shown, through brain imaging techniques, that practising mindfulness activates certain brain regions leading to a greater sense of calmness and well-being [53]. Mindfulness exercises were found to support managing day-to-day personal and professional problems [126, 357], and increase empathy and work engagement while mitigating compassion fatigue and burnout syndroms [186]. Further, they can improve executive attention, working memory, visuo-spatial processing [7, 650], and enhances creativity [131, 265]. This, in turn, can support flow and presence [635]. Moreover, mindfulness directly impacts mental well-being positively [91, 243, 458].

Designing for Mindfulness. In HCI, recent work has shown increasing interest in using VR for mindful relaxation tasks [21]. The review by Arpaia et al. showed that VR increased relaxation and self-efficacy, reduced mind wandering, and preserved attention resources when used for mindfulness practice. Some work also explored the connection between tangible interfaces and mindful self-awareness. One notable example is by Zhu et al. [654], who combined a physical mindfulness prototype with a digital application for stress reduction. Drawing on these insights into the benefits of passive haptic feedback for mindful exercises, paper B explores more specifically how haptics and self-awareness are linked in a mindfulness task.

Further, scholars have explored how sensor data and biosignals can be used to support mindful behaviour for self-awareness. For example, Liu et al. [327] combined an AR lens with a Muse 2 headband to measure biosignals. This setup was used for a co-located mindfulness experience, where one participant used the signals to guide the other through a meditation task. Similarly, Amores-Fernandez et al. [15] use real-time EEG data from a Muse headband to measure concentration, and only if a threshold is reached are users able to interact with the virtual environment. They found that this approach increased mindfulness and concentration skills while engaging users. These approaches underline how extending the virtual environment with user-specific data and feedback benefits self-awareness. As another example, both visuals and the sound of the virtual environment were mapped to the breathing patterns of users in real time. Prpa et al. [440] have created aesthetically pleasing underwater scenarios, where lighting, movement and sound visualised users' breathing, which increased the efficiency of the relaxing breathing task [440]. This example highlights how mindful tasks benefit from actively designing for auditively and visually pleasing virtual environments. Yet, the following question remains unanswered: how does addressing other senses relate to mindful self-awareness tasks?

Inspired by this work, I explore the impact of tactile and auditory feedback on a mindfulness state in paper *B - Haptics*. The focus hereby lies on a mindfulness exercise to promote awareness of the surroundings and of the internal states. Further, paper *C - VeatherReflect* visualises user-specific health data, such as stress levels, using the metaphor of various weather scenarios. Thereby aiming to foster mindfulness and self-awareness.

2.3.2 Self-Reflection and Rumination

Another self-care activity this dissertation focuses on is promoting self-reflection. Reflection plays a fundamental role in self-care and well-being [558]. While, again, there is not a single definition, this dissertation follows the one by Grant et al. [221]:

> We refer to self-reflection as the inspection and evaluation of one's thoughts, feelings, and behaviour [221].

Self-reflection can also be loosely defined as understanding, thinking about potential courses of action, and one's role within these courses of action [511]. Self-reflection also refers to the depth of understanding one's internal states [221]. When self-reflecting, people take their past experiences into account to evaluate their momentary internal states, gain insights about themselves or enhance their performance [214, 221]. Thus, by helping people to understand their reactions and the reasons behind them, self-reflection contributes to self-awareness.

Reflection-in-Action and Reflection-on-Action. Most widespread is the foundational work on reflection by Schön [511]. Schön is often called the 'founding father' of current reflective practice [384]. Schön et al. [511] explain that when facing a surprising aspect, people can choose to either ignore the emotions of surprise, or they can start a process of reflection. This process can be distinguished in reflection-in-action and reflection-on-action. The former happens during an (inter)action. It is a spontaneous ability to "think on our feet" [511]. In contrast, reflection-on-action is conducted in retrospect after the action has been concluded. By thinking back on an experience, the action (or experience) itself becomes an object of reflection. Bolton and Delderfield [74] emphasise that reflection-on-action increases the effectiveness of reflection-in-action.

Both types of reflection, reflection-in-action and reflection-on-action, can shift former implicit knowledge to the conscious level, thereby making it explicit and communicable to oneself and others [511]. Reflection is considered to be helpful [372] as it can lead to more self-insight [49], support life changes [554], and benefit health, well-being and personal growth [92, 337, 539].

Levels of Reflection. Fleck and Fitzpatrick [195] have detailed a nuanced framework comprising five consecutive levels of reflection, which serves to categorise the depths of reflection and its potential outcomes. These five levels can occur through both reflection-in-action and reflection-on-action. It provides a structured framework to understand the processes and impacts of reflective practices and was used in papers *E - SelVReflect* and *F - MoodShaper* to assess the outcome of self-reflection prompted by the subsequent prototype of VR-based SCT.

Based on Fleck and Fitzpatrick [195], in level 0 (Description) people simply describe what has happened without reflecting on it. In level 1 (Reflective Description), reflection reinforces people's existing perspectives. When progressing to level 2 (Dialogic Reflection), people change their point of view and discover new approaches, strategies or perceptions related to the subject of their reflection. For instance, they might discover a new way of perceiving negative emotions and how to manage them. If this results in a fundamental shift in thinking and self-perception and a change in behaviour, then people have reached level 3 (Transformative Reflection). Lastly, level 4 (Critical Reflection) describes a more meta-level, in which the wider picture, such as societal impact, is considered.

Thus, overall, reflection is assigned an influential role for self-care and well-being [558]. Yet, reflection can be a challenging activity and often does not occur automatically, but needs to be encouraged from the outside [539]. For instance, many mental health professionals guide their clients throughout the reflection process by asking questions or prompting their clients to talk or draw a certain situation or emotion, while fostering an atmosphere of creativity, freedom, and playfulness [143, 478]. Additionally, family, friends, media, and technology can serve as catalysts for self-reflection. Given technology's potential to encourage reflective thinking, designing technology for this purpose has become and ever-increasing interest of HCI researchers [195].

Rumination. However, when aiming to design for reflection-enhancing technologies, one key challenge is to prevent rumination, as rumination undermines the effectiveness of those technologies [178]. If technology cannot promote self-reflection successfully, people might dwell on negative thoughts such as past mistakes or being not good enough. This is what is called rumination in technical terms. Its working definition for this dissertation is a conglomerate of several definitions, as outlined in the following:

> Rumination is when people get stuck in negative emotional thought cycles [213]. Niess et al. [397], Eikey et al. [178], and Trapnell and Campbell [586] highlight that rumination can be considered a counterpoint to the positive activity of self-reflection.

When ruminating, a decrease in self-awareness or self-compassion, defined as being kind to oneself, was perceived [486]. Further, it disburses stress hormones and increases the stress response circuit [486]. It can result in harmful coping behaviours such as overeating or excessive alcohol consumption [487, 213], and can contribute to the onset of depression [260] while also prolonging the time it takes to recover from negative experiences [570]. Consequently, one of the key challenges in HCI research is how to design technologies that are particularly aimed to enhance reflection [555] while preventing rumination [178].

Designing for Self-Reflection. Considering current research for reflection-enhancing technologies in HCI, many applications do not specifically design for reflection; instead, reflection rather happens as a byproduct [304, 555]. To elaborate, in regard to VR, most applications investigate reflection together with another concept, for example, empathy skills (e.g. [555]), learning (e.g. [304]), or storytelling (e.g. [29]), but not with a specific focus on teaching the development of self-reflective skills. Additionally, Slovak et al. [539] criticised the framework about technology design for reflection offered by Schön et al. [505], as it does not directly addresses how technologies can support reflective processes. Yet, as noted in the systematic review by Baumer and subsequent studies [49, 539, 59], more than 70% of HCI papers rely on their framework. Consequently, concrete design ideas of how to design VR-based applications helping to self-reflect on internal states are lacking.

Some approaches in HCI that have tried to tackle this research gap have established frameworks and specific key design resources such as temporal perspective, conversation, comparison, and discovery [61]. However, the open challenge remains how to pinpoint specific contexts where these resources can be most effectively applied. In the context of VR, the model called "Readiness for reflection, Immersive estrangement, Observation and re-examination, Repatterning of knowledge", short RIOR, by Jian and Ahmadpour [266] presents a novel approach to designing for reflection. They apply a theatrical perspective to enhance reflection in VR. This model suggests various techniques to foster reflection, including changing the physical perspective from which users view content and incorporating personal item representations. However, the RIOR model does not provide specific design recommendations.

Instead, apart from personal informatics, most systems in HCI whose design aim is to facilitate reflection rely on conversational interfaces or chatbots that prompt users for reflection and guide and scaffold self-awareness [318]. Conversational interfaces are already often used for mental health and well-being support [203]. For instance, MoodAdaptor [299] is a web-based application designed as a technology mediating reflection by prompting participants to reflect on past memories which can regulate their current mood. They found that thinking about memories opposite to the current mood led to a more neutral mood in the moment. For instance, when in a good mood and thinking about negative memories, participants tended to feel less positive, and when feeling rather down but thinking about positive memories, it enhanced their well-being. Another example is Robota [295], a conversational agent using a mixture of chat and voice interaction to support journaling, self-reflection and learning at the workplace. This agent asks questions and chats with users using Slack, and they found that this modification helped users to reflect. Comparably little research has explored conversational interfaces in VR [377].

Besides conventional interfaces for reflection, there have been a few studies that demonstrate the connections between reflection and personal informatics using VR. Two notable examples are studies conducted by Egan et al. [177] and Yoo et al. [644]. Egan et al. [177] introduced health data such as heart rate data as a reliable way to measure the quality of a virtual environment (VE), while Yoo et al. [644] developed a VR dashboard that offers users a reflective overview of their personal sports data, such as step count. However, while these approaches can inspire, they do not present specific design recommendations when designing VR-based SCTs for reflecting on internal states.

To address these research gaps, VR prototypes designed for paper *C - VeatherReflect* and *E - SelVReflect* are specifically designed to facilitate self-reflection, in particular on complex personal health data (*C - VeatherReflect*) and personal emotional challenges such as a break-up (*E - SelVReflect*). Both are designed to target reflection-in-action [511]. They are designed with specific key design resources in mind [61], promoting comparison in paper *C - VeatherReflect* by comparing two forms of visualising health data, such as stress levels, with each other. The prototype of paper E - SelVReflect facilitates the visualisation of a temporal perspective, conversation and discovery by being guided through a voice-based interface, inspired by related work on conversational interfaces. The RIOR model [266] was addressed in paper *C - VeatherReflect* by including personal items, in that case, personal stress data.

2.3.3 Self-Expression

This dissertation focuses on one other self-care activity, which is (emotional) *self-expression.* Compared to self-care activities aimed towards mindfulness or self-reflection, even less research has specifically explored self-expression in HCI [290], a research gap addressed by this dissertation.

> Self-expression is defined in this dissertation as communicating inner emotional states, thoughts and beliefs towards the outside, following notions by Gross et al. [228]. The focus is thereby on artistic emotional expression inspired by art therapy [335].

Self-expression can range from nonverbal cues such as facial expressions, to brief exclamations of awe or surprise, and more complex behaviours like naming emotions, journaling, or drawing. When specifically related to emotions, it is termed emotional self-expression. This concept is fundamental to many therapeutic approaches, as visualising and reconstructing internal states can enhance reflection and increase positive affect, as postulated by the Expressive Therapies Continuum [275]. Effectively, it forms the basis of Cognitive-Behavioural Therapy [246], Mindfulness-Based Cognitive Therapy [601], and Art Therapy [238, 343], the latter being a major inspiration for research in this dissertation.

In that regard, self-expression, particularly through artistic means, offers an alternative to verbal communication for those who find it difficult to articulate their emotions [455]. Art as a form of self-expression has been important to humankind for centuries [287], having been used already in cave paintings 40.000 years ago. Art-making can be considered an experiential activity that in itself constitutes meaning through two aspects: first, through its process and second also offering a tangible object serving as a reminder [148]. Both process and outcome can open people up towards their emotions and thoughts, thus being a source of self-awareness [148]. This is also partly due to the toolset that is used in artistic self-expression. To describe this with the words of Eric Booth [76]:

> "Even though our views of art have changed and our equipment for arts has diversified over the millennia, we still haven't improved on those original tools (call them technologies) that ancient cave painters knew about: metaphor, improvisation, following impulses, making things that hold personal meaning, exploring the worthwhile things others have made, creating rituals in a special place."

As such, even seemingly aimless art activities such as doodling can be considered a contemplative self-care activity [136, 515].

Benefits of Self-Expression. Besides benefitting from the process of art-making as a contemplative, meditative and engaging activity that can lead to flow [141], artistic self-expression can also support self-reflection. To elaborate, a fundamental theory in art therapy, the Expressive Therapies Continuum [275], states that drawing can be used as a reflective activity, which can generate conceptual meaning. It further conceptualises the relationship between drawing and how feelings of positive affect occur through such expressive activities, in line with other research emphasising that it creates pleasure [268]. Additionally, artistic self-expression can build intrinsic motivation towards goal-setting [335], and improve one's self-efficacy [287]. When used long-term, further research has emphasised its benefits for increasing mood and mental health [562] as well as for improving health and well-being [590]. Thus, self-expression can provide both a hedonic as well as an eudaimonic experience for mental well-being. Importantly, self-care activities like mindfulness and self-reflection are inwardly directed, leading to self-awareness or other outcomes either during or immediately following the activity. In contrast, self-expression has a conceptually different approach as it requires an intermediary step or method. Solely through the process of creating, whether crafting words or art, one is able to delve into self-awareness.

Designing for Self-Expression. However, taking this inspiration from art therapy into account, only recently the design for emotional expression has begun. To elaborate, in a scoping review about VR usage to promote positive change from 2018 [290], only 2 of 33 publications in HCI aimed to facilitate self-expression. Since then, interest in that area has increased across technologies. For instance, Coward et al.[136] explored the benefits of doodling as a self-care tool in reality and Liu et al. [328] aim to provide digitally-supported mindfulness through a creative artistic approach (self-expression) through finger painting in AR.

Nonetheless, research into the use of VR as a tool for artmaking in therapeutic contexts was largely inactive from 2011 to 2020 [239]. In fact, 73% of the reviewed papers were published between 2020 and 2022. Art making in VR has been shown to have similar physiological and psychological effects as 2D drawing, including reduced heart rate and skin conductance, decreased stress and anxiety, and an increase in positive affect [460]. However, VR bears unique possibilities for engaging kinesthetic, visual, and aural senses and seeing the VR drawing from multiple spatial perspectives, which can facilitate reflection and promotes engagement in a way not possible in reality [237].

As some examples of self-expression in VR, Cheung et al. [120] empowered people with dementia to collaboratively create art expressing their emotions using the means of VR. Further, Semsioglu et al. [516] used VR to facilitate emotional expression through the so-called 'Isles of Emotions,' where participants created and discussed virtual islands representing their emotions. This approach was found to enhance self-awareness, emotional expression, and communication skills. However, creative self-expression was restricted to a 3D modelling tool, limiting autonomous possibilities. Overall, research on VR-based SCTs that promote artistic emotional expression remains limited, highlighting the need for further exploration and development to broaden the variety of effective VR-based self-expression tools.

> Addressing this research gap, papers *D - MoodWorlds*, *E - SelVReflect*, and *F - MoodShaper* use artistic self-expression through independently designing the VR environment by using a VR drawing toolset. Rather than restricting to 3D modelling [516], and incorporating actions similar to finger painting in AR [328] with the aim to express emotions (e.g. [120, 516]), we created a toolset allowing for a mix of using pre-defined environments, drawing with different brushes, 3D modelling and animations, to extend the variety of tools supporting creative self-awareness.

2.3.4 Thinking Beyond

The goals that self-care activities aim to promote differ widely, including improving their overall well-being (e.g. [342]), providing a space to just exist, explore and to be in awe with (e.g. [443]), encouraging deeper self-awareness (e.g. [318]), guiding through managing mental health challenges such as anxiety [183] or reducing health risk behaviours [439]. Another main goal seems to be to teach specific self-care strategies that are also applicable to reality, including mindful breathing for relaxation purposes (e.g. [440, 522]), how to be self-compassionate (e.g. [317]), or how to express and regulate emotions through artistic self-expression (e.g. [136]).

Despite the broad variety of supporting different self-care goals, the prototype examples of this section have also highlighted that many applications focus on providing a mindful and relaxing experience, heavily inspired by MBSR [601]. There is still surprisingly little research supporting the understanding of one's internal states apart from MBSR. This notion is backed by findings of a review from Riches et al. [459] who criticise that a focus on introspective awareness and decentering are underrepresented in literature.

To address this research gap, papers *C - VeatherReflect*, *D - MoodWorlds*, *E - SelVReflect*, and *F - MoodShaper* specifically endeavour to enhance introspective awareness and broaden the research on self-exploration beyond MBSR. While paper *B - Haptics* explores mindfulness practice, the focus lies on using mindfulness not for relaxation but for increasing self-awareness and identifying thoughts and emotions. Paper *C -*

VeatherReflect promotes reflection of health data, papers *D - MoodWorlds*, *E - SelVReflect*, and *F - MoodShaper* utilise the method of self-expression to visualise emotions, to learn from personal challenges (paper *E - SelVReflect*) and develop emotion regulation skills (paper *F - MoodShaper*).

Furthermore, this section has underscored the conceptual and practical interconnectedness of self-care activities within prototype designs. For instance, a system designed primarily for artistic self-expression can also facilitate mindfulness and reflective exercises, integrating multiple therapeutic elements into a cohesive activity [275, 515]. Consequently, the outcome is often reported in regard to a specific self-care activity, such as self-reflection, although the prototype was not initially designed as such and might lack key design resources for that particular self-care activity [555]. While achieving more positive outcomes than initially planned is generally advantageous, it is crucial to design features that do not inadvertently lead to negative effects commonly seen in associated practices. For instance, an application designed to foster self-expression should be careful not to unintentionally encourage rumination, which can be a risk due to the interconnectedness of self-care activities. Therefore, in this thesis, the intended design and the observed outcomes are treated as distinct concepts and are reported separately to ensure clarity and accuracy in the findings.

2.4 Engaging Experiences: Addressing Psychological Needs

> *"Tell me and I will forget, show me and I may remember, involve me and I will understand."* – Confucius (Chinese philosopher)

Society has a rising interest in autonomously taking care of their own mental health and well-being, expressing a desire to be empowered, to have the agency and autonomy for self-care [99, 655]. Having this foundational motivation can be essential to engage in self-care practices and can influence the effectiveness of self-care activities as well. At the same time, designing SCT in an engaging way can increase the overall motivation to continue using the application and to integrate self-care behaviours into the everyday routine, highlighting the cyclical relationship between engagement and self-care practice.

However, engagement is a concept that is often used interchangeably with other aspects such as agency and autonomy, lacking consistent differentiation from each other both in psychological and HCI literature [58]. To elaborate, Lukoff et al. [334] have described the connection between these concepts as follows: "The sense of agency matters in its own right. Feeling in control of one's actions is integral to autonomy, one of the three basic human needs outlined in self-determination theory". Lukoff et al. [334] here emphasise the importance of the aforementioned concepts in regard to integral or human psychological needs, which in turn form the basis for being motivated.

Consequently, this section navigates through the intricate landscape of engagement, exploring its relation to continued use and effective self-care. It also highlights the importance of addressing psychological needs, first and foremost autonomy, in design.

2.4.1 Engagement

While there circulate more than 100 definitions [165], for the scope of this thesis, the working definition of engagement consists of a mix of definitions from O'Brien and Tom. [416], Laurel [312] and Doherty and Doherty [165], resulting in the following:

> Engagement is an empowering quality of user experience with technology characterised by an aesthetic and sensory appeal, interactivity, perceived control, awareness, motivation, interest, and an emotional state of mind necessary to enjoy an intervention.

These definitions highlight the subjective nature of engagement, which can be enhanced by delivering a positive user experience (UX) through technology [165]. However, its individual perception makes it challenging to measure [416]. To infer the extent to which users are engaged with the system, one can measure aspects of UX such as usability, emotional response, and overall satisfaction [165]. As such, prototypes presented in this dissertation often evaluate UX. This thesis applies the following working definition of UX:

> The concept of user experience encompasses the full range of emotions, thoughts, and behaviours that individuals encounter when interacting with a product or system [506].

Designing VR experiences that foster a positive UX can ensure that individuals are left with favourable impressions during and after the experience that can motivate users for continued use [288]. UX is influenced by three major factors: the device, the interaction and the user [581]. The device refers to the technical dimensions that facilitate immersion [504, 571]. Interaction describes the technical possibilities of people to affect virtual environments through controllers or hand gestures [288], as well as design elements enhancing realism and aesthetics, such as modalities, that can improve interaction [288]. Challenges in usability, however, can hinder UX and engagement in VR [244]. Lastly, UX and engagement are always subjectively perceived by the user on an inter- and intrapersonal level. Thereby, increased presence positively correlates with UX, engagement and the intention for continued use [244].

Besides UX, the definition of engagement also points towards several other relevant concepts for this thesis, namely perceived control, also called, autonomy and theories of motivation. These will be elaborated on in detail in the following.

> This dissertation focuses on designing engaging interactive scenarios which provide a good UX in all self-care systems provided (papers B, C, D, E, F). It specifies and extends the METUX model to VR-based SCTs, aiming to address psychological needs across all spheres of experience.

2.4.2 Addressing Psychological Needs

One prominent theory which explores human engagement, motivation and personality in social contexts is the self-determination-theory (SDT) [152, 481, 483]. SDT is a broad psychological framework focusing on how human behaviours are motivated and self-determined from a macro-level perspective [152].

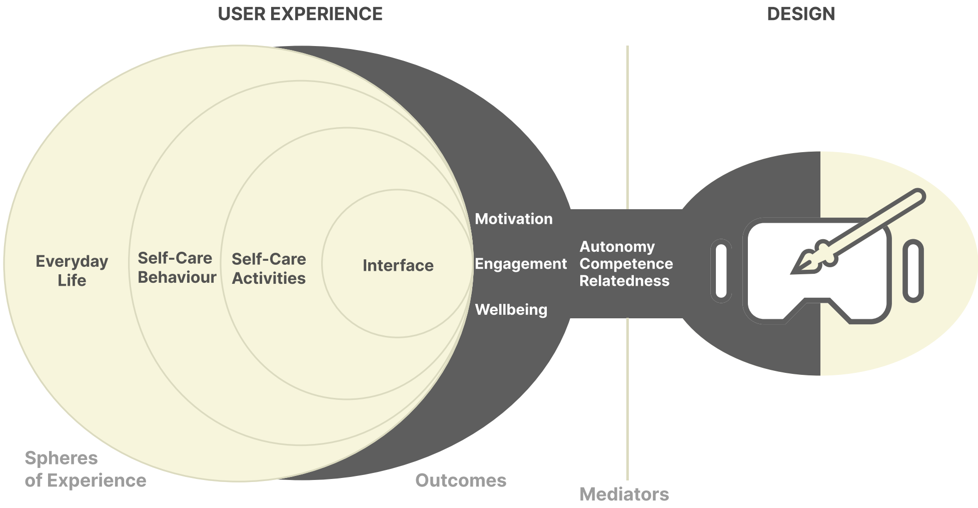

Figure 2.2: Spheres of experience in the field of well-being. Adapted from the METUX Model [427] and extended to fit to this dissertation's research aim.

> SDT posits that people are profoundly motivated by three basic psychological needs, namely autonomy, competence and relatedness, which can enhance self-determination, self-motivation and mental health [152].

These elements are acknowledged as intrinsic values, essential for fulfilling fundamental psychological needs that are universally inherent to all humans, and that can enhance engagement.

Autonomy. Autonomy refers to people's need to feel in control of their actions and choices which should feel authentic and align with their own perception of self. It relies on the ability to act, thus having agency over one's life [278, 527].

> Autonomy is defined as *"the ability to function independently"* [216], the capacity to make independent choices informed by personal principles [547], and being self-governing [326].

Customising VR has been shown to be an empowering activity that has a positive effect on UX, sense of autonomy and enjoyment when tested to motivate physical rehabilitation [146, 38]. Further, by providing safe environments that engage users to explore and autonomously interact, VR can empower and motivate users to conduct life choices [464]. Other studies investigated the importance of interactions in VR as a factor of agency. For instance, Voigt-Antons et al. [603] found that after negative emotions were induced in a VR horror game, increased interaction possibilities in a VR natural setting reduced arousal and increased valence significantly faster than when people could not interact in the virtual environment. Similarly, Jicol et al. [267] followed the working definition of agency as an interaction possibility in VR. They explored the complex interplay of emotion, agency and presence in VR. They induced either happiness or fear in users through different virtual scenarios, and being able to interact with a dog or a beast according to the condition. They found that agency had a significant positive effect on presence and, as presence positively correlated with emotions, further moderated the effect of emotion on presence. Along those lines, other research emphasised that interacting as a form of agency can also be considered as the act of self-creating the virtual environment. For instance, in Semsioglu et al. [516], users were empowered by using 3D drawing in VR to express their current emotional state, thus creating isles of emotions that promoted their autonomy and agency.

Competence. Competence is defined as the need to feel a sense of mastery and skill when interacting with the environment or undertaking challenges [483], meaning, that people want to feel as if their interactions are effective. To that end, competence also benefits from increased self-knowledge (as detailed explained in Section 2.5.2) and the feeling of self-efficacy, which can motivate future change [214].

Competence and self-efficacy are interrelated. Linked with personal growth, self-efficacy describes the belief and confidence in one's ability to complete tasks, achieve goals and handle similar situations in the future in a better way [37]. It also refers to the belief to succeed, such as feeling proficient in using self-care activities or performing desired behaviours for mental well-being [37]. Along the same lines, Scott et al. [512] stress that it reflects the confidence in maintaining control over the own motivations, behaviours and the social environment. One effective way to increase self-efficacy is to be able to enjoy mastery experiences. Mastery experiences provide people with successful completion of a task or overcoming a challenge that promotes their belief in their own competence. This further encourages a feeling of empowerment [499], closing the circle.

Relatedness. The last psychological need is relatedness. It focuses on the need to have meaningful relationships and interactions with others, feel connected to other people, and give and receive care [483]. Although not a primary focus of this dissertation, relatedness should be emphasised in future research on multi-user VR-based SCT. For detailed ideas, I refer to Section 3.4.2.

Psychological Needs in HCI. While meeting these three basic needs with technological design can increase motivation, the *value of motivation* predicts if motivation contributes to well-being [483]. The value of motivation ranges from extrinsically-controlled (e.g. when threatened with punishment), which does not promote well-being, to intrinsically-autonomous related to high well-being. Extrinsic motivation, which can be external rewards such as financial incentives, can, under the right circumstances, evolve towards intrinsic motivation by being internalised [482]. Intrinsic motivation refers to activities that are perceived as personally rewarding, which is the overall aim of designing self-care activities.

However, it is said that extrinsic regulation that targets autonomy can be as effective as intrinsic motivation [483], motivating the design of scaffolding opportunities as is part of RQ3 in this dissertation. This hypothesis was confirmed when applying SDT to health contexts, showing that autonomous extrinsic and intrinsic motivation both enhance the effectiveness of self-care and motivate lasting behaviour change [394]. Figure 2.3 combines the visualisation of the SDT-continuum [482] with the value of motivation [483] and provides illustrating examples based on users' experiences, adapted from [427]. Work of this dissertation targets extrinsic motivation supporting autonomy, for instance through encouraging affirmative prompts, and intrinsic motivation, highlighted in Figure 2.3.

Given that SDT is a comprehensive macro-theory of motivation crucial for ensuring continued use, it is one key goal for many designers and has seen broad applications across various fields within HCI. For example, it has been applied to the design of video games [480] and conversational interfaces [642] to create experiences that enhance motivation. In regard to VR, one notable work is by Ahmadpour et al. [5]. They compared static to open-world VR settings in an immersive exercise VR game and realised that enjoyment in the open-world setting positively correlates with psychological needs. Yet, they also postulate that more research is needed to address psychological needs in VR.

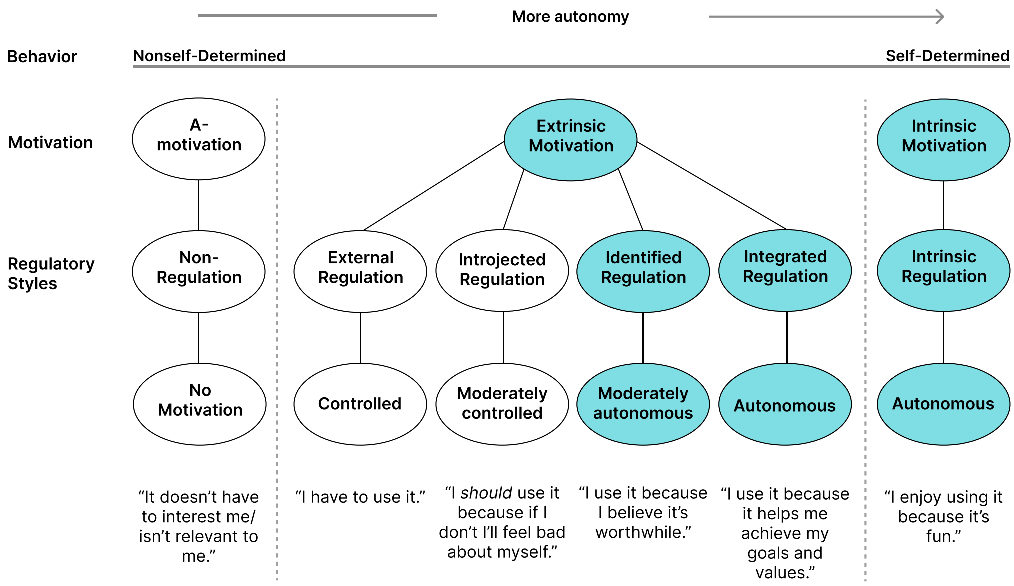

Figure 2.3: Adapted from The Self-Determination Continuum [482], extended with the value of motivation continuum [483], and illustrated by users' experiences, adapted from Peters et al. [427]. This dissertation addresses highlighted areas.

Mastery experiences are aimed to be provided in papers B, D, E and F of this thesis. Self-efficacy is in particular measured by standardised questionnaires in paper E. Papers D, E, and F focus on providing people with the autonomy to create their virtual environment themselves, and on providing competence by giving them an easy-to-use artistic tool set in VR. In order to motivate people, the prototypes developed in this thesis (papers B, C, D, E and F) all aim for identified and integrated extrinsic motivation, and ideally for intrinsic motivation by showing users how important and engaging self-care activities can be. Strategies how to reach this aim differ per paper.
For instance, Paper F generates extrinsic motivation by visually representing the relief experienced after completing an emotion regulation task, thereby aiming to evoke feelings of accomplishment. It also presents an 'incentive' by reintroducing the positive and meaningful virtual world created earlier, rewarding the successfuly process of regulating negative emotions. Through integrating autonomous design, we strive to make it a meaningful and engaging experience, that can potentially also lead to intrinsic motivation to re-use the application.

2.4.3 Thinking Beyond

Overall, the aforementioned sections have highlighted the intricacies and complexity of the concepts of engagement, empowerment, agency, autonomy, psychological needs and UX. While, aiming for simplicity, this thesis presents a clear hierarchical order, considering engagement as the outcome of addressing psychological needs, research is in fact divided on how to causally order these dynamic and interrelated concepts (e.g. [256, 345]). For instance, engagement is oftentimes considered a manifestation of underlying and intrinsic motivation [233]; a motivation which is the outcome of feeling empowered and having the agency to act as well as being able to autonomously decide. However, engagement can also be seen as the reason and starting point, because without engagement, the feeling of empowerment and autonomy would not arise, and furthermore, engagement in meaningful activities can further enhance a person's sense of empowerment and agency [165].

This ambiguity of definitions is also mirrored in HCI research. For instance, Schneider et al. [499] conducted a systematic review of 54 HCI papers published at CHI, highlighting the ongoing conceptual unclarity of the term empowerment. Doherty and Doherty [165] included 351 HCI publications in their survey and found more than 100 different definitions and interpretations of engagement [165]. Similarly, Bennett et al. [58] reviewed more than 30 years of HCI research on autonomy and agency, showing that these terms are used as interchangeable umbrella terms. I acknowledge that the prevailing unclarity, non-distinction and interconnectedness of psychologically relevant concepts can also be found throughout this dissertation. Despite the unclarity, all reviews emphasise the desirability of those concepts (as part of design and outcome of good design) when designing technology in HCI, also holding true when designing for mental health problems and self-care [164]. Effectively, a big focus was placed throughout this dissertation on how to empower and engage users, building agency and autonomy through careful design.

To that end, this dissertation is inspired by the METUX model by Peters et al. [427], providing a framework which shows how all these concepts are linked with design. Their METUX model diagram shows how designing for the basic psychological needs of autonomy, competence and relatedness can positively influence UX, engagement, motivation and personal thriving in different spheres of experience. The spheres encompass the usability of the interaction with the interface (e.g. intuitive use of VR controllers), how well each separate task of the application fulfils psychological needs (e.g. choice of predefined environments, integration of 3D objects), the impact it has on overall behaviour (e.g. exercising, meditation, self-care behaviour) and the impact on individual flourishing and satisfaction with life (e.g. integration of self-care behaviours into daily routines to increase overall well-being). I adapted this model to fit this dissertation's research aim, i.e. specifically investigating the design of VR-based SCTs (see Figure 2.2).

Importantly, the design of technology can and has to ensure continuous engagement and as such has to be carefully designed, including an aesthetic appeal [636]. Nonetheless, it is essential to engage in thorough discussions about the optimal level of engagement that best meets users' specific needs [636]. This question will be of essential importance throughout the dissertation. Especially Part IV, Designing VR for Scaffolding, explores how to balance engagement with other important elements necessary for creating effective self-care.

2.5 Navigating Introspection: Insights into the Process & Core Concepts

> *"Those who look outwards are dreaming, those who look inwards are awakening."* – C.G Jung (founder of analytical psychology)

For self-care, one fundamental aspect is to understand oneself better. This is a prerequisite for adapting self-care behaviour that fits to the individual lifestyle, everyday routine and personal needs. Self-care activities such as those presented before (mindfulness exercise, self-expression and self-reflection) all have the overall aim of improving self-understanding. To be more precise, all these self-care activities can facilitate becoming aware of internal states [568], of building an in-the-moment understanding of what we need to feel better, and to help the self-evaluation process [175]. In technical terms, this is called the process of introspection, with the following working definition:

> Introspection is the examination of one's internal states, thus reviewing own conscious thoughts and mental and emotional processes [100].

Through this practice, people can gain access to their mental states - including sensory, cognitive, and emotional states - which can benefit clinical mental health as well as personal growth in regard to mental well-being [297]. Additionally, introspection can enhance both the breadth and depth of information that people have about themselves [112].

Introspection, as the desired outcome of all prototypes of self-care activities presented in this dissertation, profits from three distinct but correlated concepts, that will be defined in this section, namely self-awareness, self-knowledge and cognitive change.

2.5.1 Self-Awareness

Engaging in self-care activities can support self-awareness, and self-awareness is one major component of self-care [12, 32, 104]. Related to self-awareness are the concepts of self-discovery, describing the process of becoming self-aware through unexpected significant life events and 'aha-moments' [384], and self-exploration, which is an active and ongoing process where people deliberately seek out new experiences to understand themselves better [219]. However, due to simplicity reasons, this dissertation uses self-awareness as an umbrella term, following this working definition:

> Self-awareness is defined as understanding oneself on a conscious level, recognising one's internal states [458], referring to an in-the-moment understanding of how you perceive yourself and your internal states [91].

Self-awareness theories, first and foremost developed by Duval and Wicklund [174], describe that attention can either be directed towards the environment external of the person, termed subjective self-awareness, or inwards exclusively towards the self, called *objective self-awareness*. Through objective self-awareness, when the focus shifts from the outside world towards ourselves, we experience change, by comparing our current behaviour to our self-developed internal standards and values [113]. Yet, how these experiences change, is still controversely debated over the past forty-five years [94]. Being self-aware should not be confused with being self-conscious, which is also called dispositional self-focus [113]. This rather describes the awareness of our own existence and that one has consciousness [113]. Rather, self-awareness relates to how our internal space appears at that specific moment [113]. However, one can use situational self-awareness or self-focused attention synonymously to self-awareness [113].

A review by Carden et al. [111], which is based on interpretations of self-awareness from 31 papers, identified three meta-themes of self-awareness: Components of self-awareness, how to be self-aware, and purpose of self-awareness. Components of self-awareness describe elements that people need to become consciously aware of through introspective self-awareness as they are essential for developing self-awareness. They are split into intrapersonal and interpersonal components. The first centres on the awareness of own resources and current internal states, including beliefs and values, mental state with thoughts as well as emotions, physiological responses, general personality traits and motivations [111], which could be further specified as intrinsic motivation [483]. Interpersonal components, including others' perceptions and behaviours, emphasise that self-awareness also always includes evaluating the self in comparison to extrinsic standards [111]. The second meta-theme, how to be self-aware, indicates that self-evaluation, which is tightly linked to self-reflection, is a necessary requirement to develop self-awareness. It further emphasises the dynamic process of developing self-awareness, highlighting the closeness to emotional intelligence and to a trainable experience [111]. It revolves around self-awareness as a fleeting in-the-moment result of focusing the attention to ourselves, e.g. through questioning ourselves and realising our potential for personal growth. The third meta-theme describes the purpose of self-awareness, which can be to better understand oneself as well as to understand the impact one has on others.

It was shown that self-awareness can intensify emotional states [113], and positively correlates with well-being [243, 458]. A review about self-awareness techniques also revealed that it can lead to personal growth, both in an individual setting as well as in a professional context for therapists [175]. It can further increase insight and self-knowledge [175] and can result in cognitive and behavioural change. All of those can be essential to find the determination to keep on using self-care activities and improving one's mental health.

Designing for Self-Awareness. Not a lot of research in HCI has specifically targeted self-awareness as a concept. One notable example created an awe-inspiring journey, where users experienced different scenarios ranging from a campfire to seeing the earth from space [369]. Being immersed in such spaces resulted in feelings of awe and humbleness, connectedness with nature, and becoming aware of own thoughts, intrinsic values and their role on earth. Self-awareness in VR is also linked a lot to embodiment. For instance, in a multi-user study by Glowacki et al. [217], participants collectively experienced their bodies as luminous energetic essences whose boundaries diffused with the bodies of others. This approach created transformative experiences and supported self-awareness of oneself. Both related works focus on becoming aware of one's body and intrinsic values. However, in my work, I mainly focus on supporting becoming aware of current internal states such as emotions. In that regard, some related work has used coloured hues in virtual environments as feedback for users on how they currently feel, based on real-time fMRI neurofeedback [331].

It has been established that self-awareness can be practised through self-care activities such as mindfulness, self-reflection or self-expression. The aim is to better understand internal states on a conscious level. As a long-term result of increased self-awareness, people can also reach a deeper understanding of themselves, called integrated self-knowledge and/or experience a fundamental change in their perception or behaviour, called cognitive restructuring or change. These concepts are explained in further detail in the following.

> As the target group of this thesis is laypeople in a domestic setting who potentially do not have expensive additional equipment, this thesis aims to provide accessible experiences for self-awareness through the design itself. While all self-care activities papers (B, C, D, E, F) can be considered to increase self-awareness, a specific design focus on facilitating self-awareness was placed in papers B, C, and D.

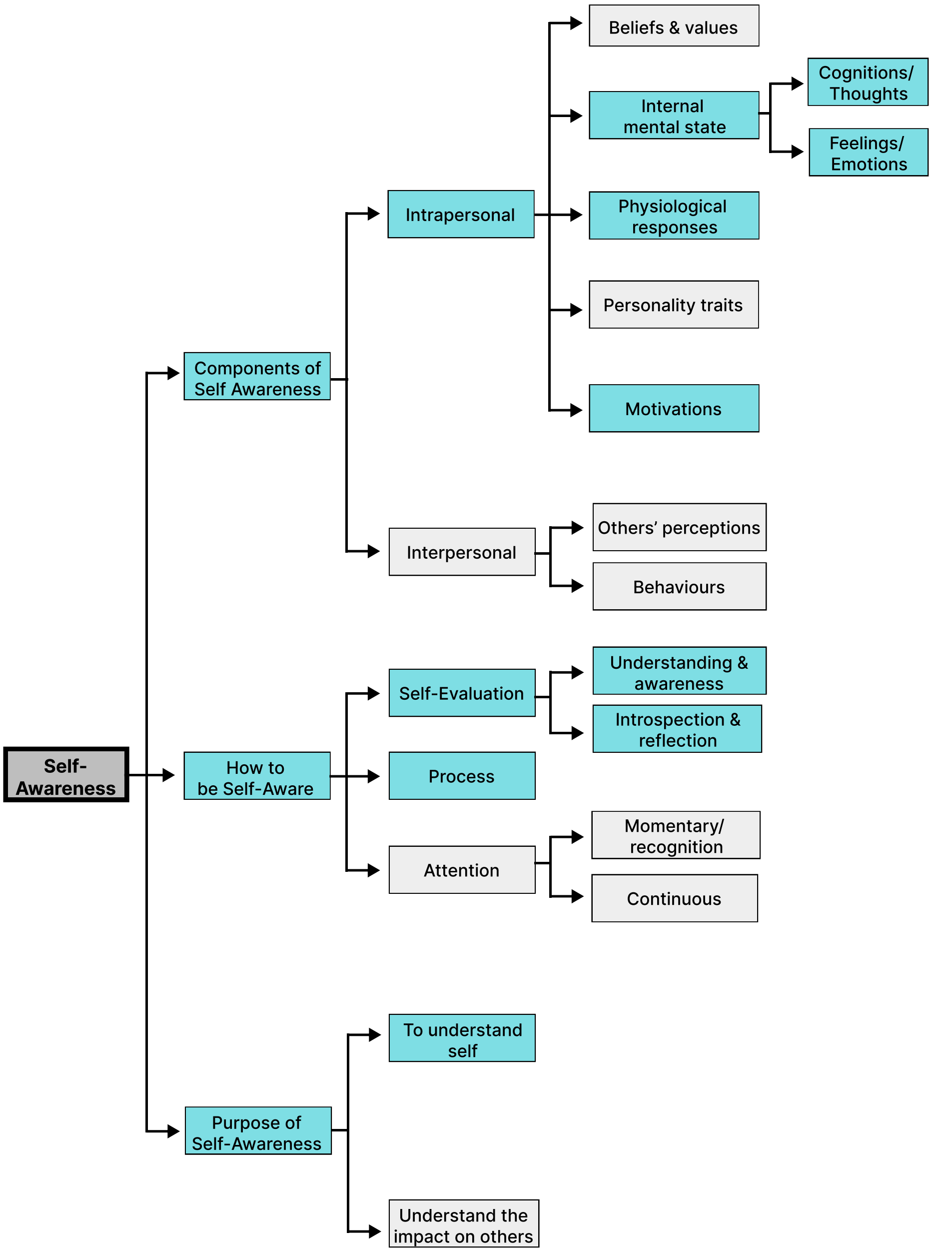

Figure 2.4: Adapted from Carden et al. [111]. Three meta-themes of self-awareness. Highlighted in colour are concepts that are addressed in this dissertation.

2.5.2 Integrated Self-Knowledge

One outcome of self-awareness is self-knowledge. In contrast to self-awareness, which is a real-time, in-the-moment understanding of how you perceive yourself and your internal states [91], self-knowledge is a deeper and more comprehensive understanding of oneself that accumulates over time [214]. It involves knowing your own values, beliefs, motivations, desires, personality traits, and life experiences and is built through reflection on how past experiences have shaped you [214].

> This thesis follows the definition by Ghorbani et al. [214]. They defined self-knowledge as *"the ability to gain knowledge about the self, allowing a person to be aware of, understand, and recognise unconscious thoughts, emotions, motives, and behaviours".*

Thus, people can gain valuable insights about themselves through self-knowledge, facilitating a clear understanding of one's potential responses in emotionally challenging scenarios and additionally aiding in goal-setting [91, 214]. Self-knowledge is colloquially often used synonymously with insight or self-insight, although they are distinct concepts. Insight describes a sudden 'aha-moment' of clarity or a breakthrough in understanding the underlying truth about themselves or a situation that they are in, while self-knowledge describes gaining a deeper level of realisation that uncovers underlying and formerly unconscious patterns that influence thoughts and behaviours. While both insight and self-knowledge are the outcomes of self-awareness, self-knowledge is an adaptive and dynamic process accumulated over time, relating past to present [91, 214].

It was found that integrated self-knowledge positively correlates with mindfulness and self-reflection, and further with subjective well-being, self-esteem, autonomy, and competence [214]. At the same time, it can decrease depression, anxiety and stress [214]. Importantly, both sudden insight and more long-term self-knowledge can motivate intrapersonal change [458] and behaviour change that can be lasting and authentic [175].

To promote self-knowledge, technologies should empower users to effectively manage their well-being [164]. To that end, some approaches have focused on creating beautiful virtual environments that could evoke positive emotions and improve self-knowledge just by being in this space [209]. Further, a review by Zheng et al. [652] discussed how VR can reduce negative affect and anxiety and improve individual self-efficacy through a manifold of different approaches. One of those strategies for self-knowledge and self-efficacy that is important for the scope of this thesis is the benefit of using VR for autonomous storytelling [210, 211]. As people create and iteratively re-create themselves through VR [210], it can also be used to arrange memories of individual life events and challenging experiences into a cohesive story, which helps to understand and to (re-) define the self in a healthy way. The findings of this study emphasise that using VR for narrating personal events shapes the perception of being an active author of their life story, giving them confidence and self-efficacy to shape their own lives in reality [211]. Further, a positive stimulus that people might experience through VR can have positive effects in real life [209]. This notion is reinforced by other research, which has highlighted that using VR to gain cognitive clarity can contribute to personal growth and self-enhancement in reality [212], lead to self-awareness of the attitudes of the past, present and ones desired to have in the future [200], and generally to achieve healthier life experiences [534].

Inspired by this corpus of related work, this thesis aims to provide toolsets for autonomous storytelling with aesthetically pleasing environments, combining it with artistic self-expression to improve self-knowledge and improve people's way of living in real life. In particular, paper E promotes reflection upon personally challenging experiences by having participants map them out as a narrative in VR. In paper F, we invite participants to revisit an emotionally troubling event marked by intense negative feelings, offering them a way to artistically alter the portrayal of these emotions. These innovative approaches suggest ways to reframe past narratives, with the goal of empowering individuals with strategies that foster self-efficacy, positively impacting their day-to-day lives.

2.5.3 Cognitive Restructuring

As a possible effect of using self-care activities, one can experience some form of change. When hearing *change*, many immediately think of drastic life-altering behaviour changes, such as doing sports three times a week, or starting every morning with yoga and meditation. Yet, instead of prescriptive strategies on how to behave, a prevailing idea in psychology is that these changes in self-care behaviour are preceded and influenced by changes in cognition by modifying people's behaviour-related thoughts, feelings and goals [192]. It was found that health interventions that had a medium to large effect on changing cognition (e.g. increasing the belief about the positive and negative consequences of a self-care activity) resulted in significantly higher changes in related behaviour [192]. To elaborate, interventions can use two strategies, change and activation, that modify beliefs which in turn leads to behaviour changes [526]. Taking the behaviour of washing hands to prevent illnesses, interventions can either target a change in people's perception or the awareness of risks attached to not washing hands, for instance through persuasive messages or more background information from experts [526]. The other option aims to activate what people already think and how they feel about the possibility of infection, for example reminding them to wash their hands through a meaningful image in the restroom [526]. Both strategies address cognitive change and also relate to dimension two of the SCM [182]. Given the challenges associated with conducting long-term studies on behaviour change [473], it is understandable why most HCI research seems to measure short-term cognitive changes immediately following an intervention and intentions for behavioural change.

It should be noted that even without the intent for behaviour change, cognitive change is valuable, as altering one's attitudes towards aspects of a situation, regulating emotional outbursts in a better way, or feeling well-prepared to react can help deal with challenging situations.

> In that regard, this thesis adopts the principles of Metacognitive Therapy (MCT) as developed by Adrian Wells [624]. For an overview of the developments of MCT until 2023 I refer to Capobianco and Nordahl [109]. MCT focuses on *how* people can direct one's attention (situational attention) and *how* they interpret and deal with aversive thoughts and emotions (cognitive reappraisal).

MCT aims to externalise emotions and reduce rumination [624]. To achieve this, strategies encompass externalising or expressing emotions, employing attention training for emotional detachment (e.g. to consciously shift one's attention to a certain aspect which can distance people from overwhelming emotional in-situ reactions), detached mindfulness for internal awareness without response (e.g. deciding not to worry in response to an aversive thought, but to allow this thought to have its own mental space) [623], and metacognitive reframing through techniques like behavioural experiments, empathic perspective taking, and Socratic dialogue [623, 624].

Emotion Regulation. Cognitive restructuring is a core method used for *emotion regulation* (ER).

> ER involves processes, both conscious and unconscious, that modulate emotional responses to enhance functioning and well-being [78, 228, 229, 360].

ER strategies typically encompass three approaches: situational attention focusing, cognitive change or reappraisal, and response modulation, all aimed at regulating the intensity, duration, and quality of emotions, particularly negative ones by shifting one's attention, altering the perception of a situation, or regulating emotional reactions [621].

Riva et al. [465], albeit in a clinical context, highlighted the potential of VR to facilitate cognitive change by promoting structuring, altering and replacing bodily self-consciousness. Despite its potential, Slovak et al.[538] highlighted in 2015 that HCI research had not fully explored specialised technologies for supporting ER. However, empirical research in that regard only began to increase around 2018, establishing it as a relatively new area of interest within HCI [340]. More critically, seven years after Slovak et al.'s initial observation, a 2022 review [340] revealed that over 50% of the studies still predominantly address ER solely through exposure therapy. Despite its potential, Slovak et al.[538] pointed out in 2015 that HCI research had not fully explored specialised technologies for supporting ER, with significant empirical research only emerging around 2018. By 2022, seven years later, a review [340] indicated that over 50% of studies still primarily focused on ER through exposure therapy, highlighting its continued novelty within HCI. Only 2 of 49 publications broadened the field to providing psycho-education aimed at cognitive change. One teaches ER skills for adolescents [240] and the other one cognitive reappraisal for borderline personality disorders [358]. This underscores a persistent narrow focus in the field in regard to ER.

One year later, in 2023, Slovak et al. [540] again reflected on existing ER technologies, criticising that most systems do not rely on theoretical grounding from psychology, and prioritise information conveyance over the actual development of ER skills. As a reason, they identify that ER skills development requires an emotionally charged but secure environment that many researchers cannot provide.

> This thesis endeavours to address these research gaps by teaching specific ER skills for managing everyday negative emotions in a non-clinical context. It provides psycho-education and is strongly based on psychological methods used in therapy as well. This approach was specifically applied in paper F.

In regard to the method of promoting cognitive change, this thesis was inspired by the following related work. For instance, Akbas et al. [8] used VR to simulate perceptual, cognitive, affective, and social aspects of psychotic experiences, aimed to support social and emotional learning and enhance reflection. They found that their application helped in spontaneous perspective-taking, shared state of affect and taught a deeper understanding of psychotic episodes that changed the perception of some participants towards those issues. Another study by Navarro-Haro et al. [388] compared conducting mindfulness practice in VR or in reality, with the aim of regulating emotions in a high-stress situation for people experiencing anxiety. The mindfulness VR intervention yielded significantly better results in reducing symptoms of anxiety and depression and enhancing emotion regulation, mindfulness, and interoceptive awareness. However, as these examples highlight, much research focuses on cognitive change in a clinical context. One notable example closer to this thesis' aim of facilitating mental well-being is by Grieger et al. [225]. In their study, participants physically engaged with negative text messages representing negative thinking patterns. They could manipulate them by punching and trashing those messages, which led to a more positive mode of thinking and cognitive change.

Inspired by this work, paper F of this thesis also applies the technique of visual modification of negative content. However, in contrast to Grieger et al. [225], we provide less aggressive means grounded in common psychological ER strategies, and broadened the topic to general negative emotions, not only considering text messages. As a take-away from research in a more clinical context, we broaden the focus on interacting with the whole environment, both to calm people and to express negative emotions.

2.5.4 Thinking Beyond

A lot of HCI research does not explicitly state that they aim to enhance aspects of introspection. However, by designing for self-care activities such as self-reflection, many studies indirectly support introspection as an outcome of self-care practices, though they may not label it as such. This lack of consistent terminology can make it difficult to compare studies and diminish the visibility of research for those specifically searching for these terms. Therefore, this thesis strives for transparency in terminology, acknowledging that various synonyms are used across HCI research.

When searching for VR applications aiming to specifically improve cognitive change for this dissertation, I encountered comparably little research addressing this topic for mentally stable adults. Instead, more research explores how VR can enhance executive functions of neurodivergent people [169] or how to provide support for the development of emotional intelligence in children and adolescents through VR [420].

While additional support may benefit these groups, enhancing cognitive clarity and facilitating cognitive change can also greatly benefit the general population. Engaging in such strategies can proactively prevent health risk behaviours and reduce the risk of experiencing severe mental distress in the future. This remains relatively underexplored, presenting an opportunity for further investigation. Accordingly, this thesis addresses this research gap by focusing on providing self-care activities supporting introspection for mentally stable adults. It aims to provide VR experiences that foster cognitive clarity and change, potentially encouraging healthy self-care behaviours in reality.

2.6 Scaffolding

> *"Even the most self-sufficient of us need a helping hand to construct the architecture of our well-being."* – Michael J. Fox (Canadian-American actor and author)

While engagement can be fostered through catering to psychological needs [483], it is well-known that people often need encouragement and "nudges" from the outside to continuously engage in self-care activities or change their self-care behaviours. For instance, many people struggle to openly express their emotions and require support in this area [455]. Further, self-reflection can be a challenging activity that often does not occur automatically but needs to be encouraged [539].

However, receiving instructions can diminish engagement [73], and people need both the capacity and willingness to learn these skills [54]. Thus, a challenge for technologies designed to enhance self-care is to carefully balance promoting skill development and teaching users in self-care activities, all while ensuring sustained engagement and promote willingness to learn these skills. Providing this outside support but not instructing is called *scaffolding*. Originally used to describe how parents and teachers can provide dynamic support to toddlers, the metaphor of scaffolding or instructional scaffolding has since been used in other contexts as well, including interventions in higher education, science, engineering and technology [55], with the following working definition:

> Scaffolding refers to providing a framework or support that helps people to complete a task or learn a skill independently [54], for instance through asking specific questions or prompting certain actions.

To be accounted as scaffolding in contrast to instructions, Belland et al. [54] proposed four key aspects that need to be fulfilled. First, scaffolding means receiving temporary support during the intervention, not before (which would resemble instructions) and with a clear ending. Second, scaffolding should have the goal for people to learn and develop skills to be able to function independently in the future. Third, it should simplify certain elements that are not central to skill learning. At the same time, however, it should highlight the complexity of tasks. This can be done, for instance, by drawing attention to task elements that are particularly important [54, 457]. Fourth, it is essential that scaffolding still guarantees interest and engagement during the process, promoting meaningful participation and implying that people understand what success in a task actually means [54]. Thus, scaffolding has to strike a balance between increasing the ability of people to reach their goals independently (by providing a framework, guidance and support, empowering them to learn) and guaranteeing willingness in and responsibility for that process (by promoting autonomy, competence, mastery and self-efficacy).

Scaffolding Methods. To reach this goal, scaffolding can encompass several methods [54]. It can relate to the decision which specific support strategy to use, for instance teaching through modelling, demonstrating or providing examples, question-asking, prompting a certain behaviour or overseeing art-making. Another method is to break down the task into smaller entities and steering the focus to a particular sub-task to solve first. Further, the timing and intensity of scaffolding can be adjusted through dynamic assessment. Often, through asking questions and observations, the level of support is determined and individually adjusted. One prominent method in regard to timing is the so-called 'fading', which describes gradually removing support over time. Fading refers to lessening the intensity and frequency of scaffolding in order to shift the responsibility gradually from the provider to the scaffold receiver. Another method for scaffolding is also to provide information, constructive feedback and encouragement through positive affirmations targeting the motivation of people. The most effective setting in which those methods are used is one-to-one scaffolding [54].

Types of Scaffolding. In a clinical setting, therapists stand out as the primary source for external scaffolding, but conversing with friends or family also accounts for one-to-one scaffolding. Therapists provide a supportive framework to guide their clients towards a desired goal. Within their sessions, therapists often also address another pillar of self-care activities, namely "promoting knowledge and health literacy", which is also often called providing psycho-education. Besides talking to people, we can also gain one-to-one scaffolding from books, movies, podcasts and tutorials promoting behaviour change. Another way is peer-to-peer scaffolding, which often happens in classrooms, or through collaborative technologies such as online chatrooms or websites where one can seek support and gain other perspectives from a group of people, for instance, in relation to mental health issues [379, 410].

> Lastly, there is computer-based scaffolding, in which technology (such as VR) provides assistance and guides skill learning [54].

Dynamic assessment with this form of scaffolding is challenging, as it relies more heavily on self-reflection than on observation. Designing computer-based scaffolding has different goals depending on the theoretical framework in mind, for an overview I refer to

Belland et al. [55]. More importantly, it is essential to characterise the target skill that should be supported, understand the user group, include information such as existing prior and cultural knowledge, predict how such a system will be used, which subskills are necessary, and in which situations the system will most likely be used. Only then designers are able to design strategies to support computer-based scaffolding.

Notably, scaffolding does not only relate to providing specific strategies for skill development. Instead, also the way that technologies are designed can already scaffold, based on considerations by Verbeek [595]. As detailed described in Section 2.1, computer-based scaffolding can influence people's perception of the world and themselves (hermeneutic scaffolding), as well as prompt a certain behaviour (pragmatic scaffolding) through their design.

Scaffolding in HCI. In HCI research, most applications apply conversational interfaces or voice assistants to provide voice-based scaffolding, as they were found to be effective in guiding through complex tasks [452, 451, 630]. self-awareness and well-being support are fitting examples of such a complex task. Examples for voice-based scaffolding include work by Kocielnik et al., who developed conversational reflection companions as mobile applications that delivered adaptive dialogues and graphs. They were successfully used to enhance reflection on data from physical activities [296] and on workplace self-care behaviour [295]. More recently, artificial intelligence and large language models were leveraged for scaffolding purposes. They create more adaptive dialogue options to help analyse mental health data [641], provide psycho-education and psychiatric support [16, 444], and guide personal emotional reflection [577].

In VR, Shamekhi et al. [522] built a virtual meditation coach, which is an interactive automated conversational agent that supports users in deep breathing. The agent reacts to users' breathing patterns measured by a respiration sensor. They explored three specific techniques and found that personal adaptive guidance increased relaxation, mindfulness meditation and reduced anxiety better than 2D video counterparts. Overall, the meditation coach was proven to be effective in replacing one-to-one scaffolding. However, the VR meditation coach [522] does not scaffold open-ended complex tasks such as self-awareness, and there is a lack of design recommendations how to successfully translate mobile or web conversational interfaces to VR with that aim in mind.

Additionally, other approaches in VR use some form of visual scaffolding. Previously, we have already used the example of coloured hues to provide feedback to users about their internal states [331]. As another form of visual scaffolding, Prpa et al. [440] designed a virtual abstract ocean environment in which one is immersed, accompanied by a generative soundtrack. Both sounds and visuals are directly mapped to the user's breathing patterns, providing feedback on the current breathing rhythm and aiming to deepen breathing patterns. With that approach, they provide visual and auditive scaffolding, as they use a gamified approach to teach a relaxation technique. However, visual scaffolding is not yet extensively researched in HCI, and moreover, clear design recommendations on how to extend visual scaffolding to other self-awareness activities, such as guiding emotion regulation tasks, are lacking.

In this dissertation, computer-based scaffolding was provided in various ways, ranging from no scaffolding over encouraging reminders to reflective questions. In paper E, I explore voice-based scaffolding of a complex task in VR, namely reflecting on personal challenges. I further examine the impact of visual scaffolding based on metaphoric interactions in paper F.

2.7 Summary

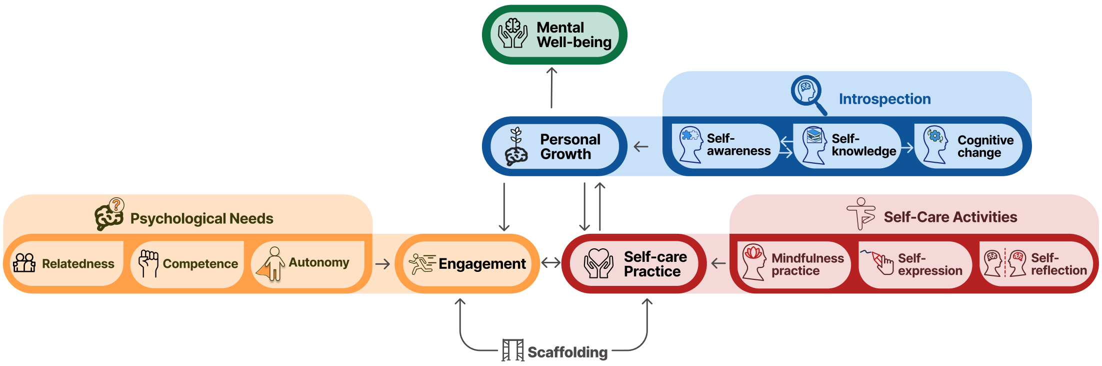

Figure 2.5: Hierarchical and cyclical process through which self-care practices enhance mental well-being. Schematical representation based on the working definitions.

The HCI community has increasingly focused on creating technologies that enhance well-being and mental health, and promote self-care concepts [66, 491, 427]. Thereby, a big focus lies on designing VR as a positive technology, describing that well-being is consciously considered in the design process [79, 105, 290, 626]. For instance, MBSR with VR is one of the most well-researched areas in HCI in that regard [655]. Comparably less research has focused on exploring engaging self-care practices for self-awareness and cognitive change [459], such as reflection support for challenging situations [555] or emotion regulation apart from exposure therapy [340]. This encourages me to broaden the scope of the investigation, exploring diverse self-care activities beyond MBSR, such as self-expression and self-reflection.

Further, this chapter has shown the complexity of definitions and interconnectedness of terminology used both in psychology and in HCI. Figure 2.5 showcases how these concepts are linked based on the chosen working definitions, arguably in a somewhat simplified manner. The overarching aim of this dissertation is to promote mental well-being (visualised in green) by exploring the design space of VR-based self-care activities (depicted in red). Specifically, it focuses on three main practices: mindfulness, self-expression, and self-reflection.

Engaging deeply in these activities can foster personal growth, particularly through facilitating aspects linked to introspection (illustrated in blue). Self-awareness is defined as the recognition of in-the-moment emotions and thoughts. As self-awareness increases, it fosters self-knowledge, deepening the understanding of one's self, values and beliefs, and vice versa. This mutual influence between self-awareness and self-knowledge can lead to cognitive changes, such as the adaptation of self-care strategies for managing everyday challenges. Personal growth then fosters mental well-being, which can increase the effectiveness of self-care practice and positively influence engagement.

Being motivated to engage in self-care practice (illustrated in orange) can increase the effectiveness of self-care activities. In turn, overall engagement is enhanced when foundational psychological needs — autonomy, competence, and relatedness — are met, for instance through the design of self-care activities, highlighting the cyclical relationship. Both engagement and self-care practice can benefit from outside encouragement, called scaffolding.

Due to the complexity and interconnectedness of concepts, many interventions target multiple self-care practices and often lead to more outcomes than initially designed for [304, 555]. This demonstrates that strict classification of well-being experiences is not always feasible. To showcase this point, I will closely examine work by Semsioglu et al. [516], which aligns conceptually with several research endeavours in this dissertation. I acknowledge that some assumptions have to be made, however, the goal is not to reach definitive conclusions but to highlight the complexities involved in conducting self-care research. In Semsioglu et al.'s study [516], participants collaboratively created virtual islands mapped onto Russell's Circumplex Model of Affect [438], which represented their emotions, and then discussed these representations. The primary goal was to facilitate autonomy, creative self-expression, and self-reflection. This creative drawing process may also qualify as a mindful activity [515, 141], enhancing engagement and promoting self-reflection. The study reports increased self-awareness and potentially self-knowledge, although these terms are not explicitly used by the authors. By using the Circumplex Model grid as visual scaffolding, the study aimed to prompt self-reflection and possibly cognitive change. Conducted in a multi-user setting, it likely also improved relatedness by fostering social connections and improving communication skills.

This example demonstrates that while the application was initially designed around three main concepts — autonomy, self-expression, and self-reflection — it resonates with all concepts explored in this thesis, despite the authors not specifically using this terminology in the paper. Similarly, my research, developed over several years with varying focuses, does not consistently use uniform terminology. Thus, this thesis includes three transition chapters to link the papers to the overarching theme of self-care. I will carefully specify which concepts each prototype addresses (e.g. *D - MoodWorlds* focuses on autonomy, self-expression, engagement, and self-awareness) and distinguish these from findings that span multiple aspects of self-care and mental well-being (e.g. *D - MoodWorlds* also enhanced self-reflection and relatedness).

Part II

DESIGN CHALLENGES

"Self-care in the digital era is not just about
unplugging. It's about plugging into the right
technology that serves your well-being."
– Arianna Huffington

Transition

Figure T1.1: Visualisation of the Research Questions: RQ1. This figure, which will be expanded in each transition chapter of parts II, III and IV, ultimately illustrates the three main research focuses of this dissertation. Currently, it depicts laypeople's interest in using VR for self-care.

The previous background chapter has highlighted the importance of designing engaging self-care experiences that facilitate introspection and promote cognitive clarity and overall mental well-being for laypeople. Figure T1.1 schematically depicts the interest of laypeople in self-care using VR as a means of support.

However, as discussed at the beginning of this dissertation, insights into how VR applications can and should be designed to support self-care are scarce. In particular, it remains unclear what difficulties laypeople face when searching consumer markets for suitable self-care applications to manage their everyday challenges. Thus, a systematic review of the quality and capacities of currently available VR-based consumer applications for self-care is needed. Particularly well-placed to assess these applications are those with expertise in self-care practices, such as psychotherapists.

Conflicts or mismatches between experts' criteria and the consumer market's offering will highlight gaps in research and design and foster a more nuanced understanding of the key challenges in designing VR-based SCTs for laypeople. The aim is to discern the necessary guidelines that VR-based SCTs should exhibit based on the comprehensive expert application review. These aims motivate the following research of Part II.

A The Role of Mobile and Virtual Reality Applications to Support Well-being: An Expert View and Systematic App Review

Abstract: Interactive technologies for autonomous mental health management are on the rise due to limited therapy access and stigma. However, most commercial mental health apps are neither theory-based nor clinically tested, and psychological theories are not easily accessible to app designers. Thus, it remains unclear if current mobile and VR mental health apps meet therapists' expectations. To address this gap, we conducted interviews ($N = 11$) to build an understanding about current therapeutic practices with a focus on emotion regulation and their applicability to mobile apps. We then conducted a systematic app review of 60 mental-health-related mobile and VR apps applying the themes identified in our interviews as an understanding lens. We draw upon the identified discrepancies to pinpoint design implications for better embedding lived therapeutic practice into mental health apps. We contribute by providing a common grounding between therapists and developers on the features and properties of well-being mobile and VR apps.

Contributions: This systematic review of VR consumer applications for self-care and mental well-being provides several key contributions. First, it establishes a common grounding and shared language for stakeholders, clarifying the requirements necessary to support users' mental self-care. Second, it presents a systematic analysis of the current state of consumer VR application design for mental well-being support among laypeople. Finally, it identifies specific key design challenges challenges, guidelines, and recommendations, incorporating the insights of professional mental health experts.

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A.1 Introduction & Motivation

Digital technologies such as mobile and virtual reality (VR) applications (apps) supporting autonomous mental health management have now established themselves on the consumer market [128]. Such technologies promise the users opportunities to improve their mental health and foster well-being [585]. While digital therapies might not be able to fully substitute psychotherapeutic treatment [128], they can be a viable alternative in cases in which starting such a treatment is difficult (e.g. because of stigmatisation [138, 365, 579, 583] or limited availability of services [138]). Thus, many people are instead turning to technological solutions that have the potential to reduce such challenges and support them in their mental health management [365, 583, 579]. Hence, there is a need to build an understanding of the current mental health technologies available on the consumer market.

Searching for *mental health* or *well-being* apps in the major app stores produces thousands of results for mobile and virtual reality (VR) apps. However, only few of these apps are evaluated through clinical trials [636] and it remains unclear if commercially available apps for mental well-being meet the expectations of mental health experts. Previous work has attempted to understand experts' perspectives on mobile health apps [332, 537] and well-being app's content [311, 556] separately. Our approach is different as we combine both, using therapists' expectations and attitudes as basis for analysing existing commercial apps. Further, we apply this experts' view on both mobile and VR apps. In contrast to similar studies of the HCI community with a focus on specific topics, e.g. learning [537] and mindfulness [333], we inquire the therapeutic intervention of engaging with feelings (i.e. emotion regulation (ER)). ER is employed in many different therapies (sec. A.2.2). Specifically, our research is guided by the following research questions (RQ):

RQ_1: How should mobile apps and VR apps support and extend the therapeutic process based on current therapeutic practice?

RQ_2: How are mobile apps and VR apps currently supporting mental health and well-being?

To answer these questions, we interviewed 11 therapists about their therapeutic practice. Grounded in the interview findings, we developed themes to systematically analyse 45 mobile and 15 VR commercially available mental health and well-being apps. Since both, mobile and VR apps, are available on the consumer market (e.g. in leading app stores), users interested in improving their well-being could potentially use them separately or together. Thus, it is valuable to analyse the opportunities and limitations of both types of apps together and explore how they can complement each other to support autonomous mental health management.

The contributions of this paper are threefold: (1) By analysing the expectations of therapists, we provide developers and scholars with a clear picture of what is needed to support users' mental self-care. (2) Through analysing different types of apps, we draw a detailed picture of the state-of-the-art features in well-being apps. This can potentially motivate therapists to augment and extend their current therapeutic methods to cater to the needs of patients outside of a therapy room. (3) By interweaving insights from both interviews with therapists and a review of commercial apps, we provide common grounding and shared language between therapists and app developers on the features and properties for well-being apps, which facilitates a productive dialogue among different stakeholders [97].

A.2 Related Work

To provide theoretical context, we first define key terms and discuss the role of feelings for well-being and therapy. We then review existing research of how mobile and VR apps are already used in therapeutic practice.

A.2.1 The Role of Feelings for Well-being and Therapy

According to the WHO, *mental health* is an integral part of health and forms the foundation for well-being and an effective functioning in society [638]. Yet, *well-being* is an abstract construct that is, for the scope of this paper, best described as *a dynamic optimal state of psychosocial functioning* [98], which is build upon five core pillars, namely positive emotion, engagement, relationships, meaning, and accomplishments [514]. *Emotions* can be classified as a circumplex of two dimensions: valence (negative to positive) and activation (low to high) [438]. Emotions can be triggered by an event or activity [179] and differ from *moods*, which are lower in intensity than emotions, last longer [419] and are often influenced by a range of factors [179]. Emotions and moods are often collectively described as *feelings* [263]. In this paper we primarily focus on apps that are working with emotion regulation (ER). ER is defined as the process by which people modify and regulate their emotions, and how they experience and express them [24, 437]. In ER therapy, one key strategy is to become emotionally aware, or using the umbrella term *engaging with feelings* [437]. In our research, we define *engaging with feelings* in regard to digital mental health management as internally *identifying*

(ID), and verbally or visually *expressing (XP)* feelings.

A.2.2 Methods of Emotion Regulation Therapy

ER is a common 'intervention' used in different forms of therapies [231], the most common being cognitive-behavioural therapy (CBT), dialectic-behavioural therapy (DBT), depth psychology or schema therapy. A shared aim of many of these psychotherapies is to provide the support and skills to overcome the difficulty of engaging with feelings. As part of such an ER intervention, generally speaking, patients learn to *identify* their feelings, *understand* the causes, and to consciously *accept* their emotional states [307].

In ER interventions, many different treatment modalities, such as artistic expressions (e.g. art therapy, role-play [461]) and psycho-education are proven to be useful to learn to engage with feelings. *Psycho-education* comprises systemic and didactic psychotherapeutic interventions with the goal to provide information, education and teach therapeutic strategies to improve well-being [552]. We believe that new technologies might offer possibilities to create spaces for therapeutic, artistic expression [90] and individually designed therapeutic environments [237]. Consequently, we strive to explore the potential and challenges of commercially available mobile and VR apps which support autonomous mental health management.

A.2.3 The Potential of Mobile and VR Technologies for Mental Health and Well-being

Smartphones have become popular for capturing well-being data (e.g. [160]). Past research works on this topic mainly focused on mental health [34], mindfulness [333, 347] and mood [103]. However, the efficacy of well-being interventions is unclear [332, 616]. Further, intervention-driven work has been subject to critique related to its appropriateness, privacy considerations and engagement [413, 584].

Similarly, HCI research has started to explore the use of VR for well-being support, given that it has proven to be an affective medium whose immersive virtual environments (IVEs) can evoke emotional states and responses similar to reality (e.g. [240, 364, 582]). Although in the mental health domain VR is mostly used as a method for exposure therapy [365], it has also been explored for other mental health related areas such as mindfulness [387], stress reduction [582, 636], role-play [240], journaling [33], , and to recreate memories [583].

The interest in commercial mobile and VR well-being systems is steadily increasing. Concurrently, research established guidelines for designing visual content of VR apps used to elicit positive change [292, 443] and outlined the design space of VR well-being apps with the means of a systematic literature review [290]. We extend these approaches by analysing commercial well-being mobile and VR apps based on insights derived from expert interviews with a specific focus on ER. In line with Gaggioli et al. [204], we define *commercial well-being apps* as "positive technologies" targeting broad masses through common app stores such as the iOS App Store or Steam.

A.3 Interviews with Therapists

We conducted semi-structured interviews that addressed the therapists' conceptualisation of well-being, which methods for engaging with feelings they use, and how they define the aim of therapy. By conducting interviews with therapists, we gain an in-depth understanding of which therapeutic methods supporting well-being are currently applied in therapeutic practice. Further, we determine what therapists expect from mobile and VR well-being apps ($\mathbf{RQ_1}$). The themes deduced from the interviews form the basis for our app analysis ($\mathbf{RQ_2}$).

A.3.1 Method

Due to the current COVID-19 pandemic, the whole study was conducted virtually. All participants were contacted via email and interviews were conducted via videoconferencing software.

Participants

We conducted interviews with $N = 11$ licensed psychotherapists from Germany ($M = 44.3$ years, $min : 26$, $max : 62$, 11 female). Participants were personally contacted via email obtained from publicly accessible websites. Though education and current occupation vary across the sample (table A.1), all participants are licensed by the state of Germany to practice psychotherapy and have further worked with patients in psychotherapy for at least two years ($M = 8.8$ years). Six participants majored in psychology (diploma or master degree) and five are educated as alternative practitioners for psychotherapy. Five participants are currently designated as psychological psychotherapists, which means that they continued training for five additional years, three as alternative practitioners for psychotherapy, three specialised in art therapy, two in depth psychology, one in osteopathy, and one works in healthcare. Three participants have a secondary, non-psychological education (P6 and P8 have majored in graphical design, P10 has majored in pedagogy). Our sample encompasses therapists with different educational backgrounds and varying specialisations. Thus, it represents a typical sample of psychotherapists in Germany that use ER in their daily psychotherapeutic work. Regardless of the specialisation, we refer to all participants collectively as "therapists", though some name themselves practitioners or clinicians. In line with most of our interviewees, we refer to people psychotherapists work with as "patients". When we discuss people utilising a mobile or VR app, regardless of their state of well-being, we refer to them as "users".

Interview Protocol

We conducted semi-structured interviews that addressed the therapists' conceptualisation of well-being, which methods for engaging with feelings they use, and how they define the aim of therapy. They further evaluated the benefits of technological aids for (private) therapeutic usage and specified features and properties they think important for both mobile and VR well-being apps. We provided the participants with a short explanation of the well-known use cases of mood tracking mobile apps and anxiety therapy VR apps. The complete interview protocol can be found in the supplementary material.

Data Analysis

Interviews were held via videoconferencing software and lasted an average of 42.3 minutes ($min: 25$, $max: 56$). Each participant was compensated with 25€. The interviews were audio-recorded, transcribed, and translated into English. For the analysis, we used a six-step process of reflexive thematic analysis with daily feedback cycles between two co-authors [85]. The results are reported using an interpretivist semi-structured approach [67].

A.3.2 Results

Based on our qualitative inquiry, three themes were derived from the data: *From Psychological Theory to Lived Practice*, *Mental Health as Holistic Concept* and *Offering a Safe Place*. Our findings are described below and illustrated with excerpts from the interviews. Specific topics and features of each theme that will be used for the app review (A.2) are marked in bold font.

Table A.1: All participants are state-approved psychotherapists in Germany and have been working in psychotherapy for at least two years. Psychological/therapeutic education and current occupation within this field differ.

	Education	Occupation
P1	alternative practitioner for psychotherapy	alternative practitioner for psychotherapy
P2	alternative practitioner for psychotherapy	alternative practitioner for psychotherapy
P3	major in psychology	psychological psychotherapist (focus on depth psychology)
P4	major in psychology	psychological psychotherapist, working in healthcare
P5	major in psychology	psychological psychotherapist
P6	alternative practitioner for psychotherapy	art therapist
P7	alternative practitioner for psychotherapy	osteopath
P8	alternative practitioner for psychotherapy	art therapist
P9	major in psychology	psychological psychotherapist (focus on depth psychology)
P10	alternative practitioner for psychotherapy	alternative practitioner for psychotherapy (focus on art therapy)
P11	major in psychology	psychological psychotherapist

From Psychological Theory to Lived Practice

The first theme derived from our data focused on how psychotherapists approach the concepts of emotions, feelings and mood in theory versus in practice. Based on psychological theory there is a clear difference between these concepts. One participant explained in more detail: *"[...] in principle we are not aware of the emotions [...]. When they become conscious, then we speak of feelings, that is the 5% that are above the water surface, considering the iceberg model"* (P9). Other participants elaborated on their conceptualisation of mood. For instance, they described mood as a baseline that shapes every emotion to a certain extent or as a *"conglomerate of different emotions"* (P4). Seven participants agreed mood is a longterm concept compared to emotions or feelings. This is further emphasised by the following statement: *"[Mood is] like a weather situation that runs through it, over several hours, over several days, or even through an entire season"* (P3). With these assessments, they agree with widely accepted theories of emotion and mood from related work (sec. A.2.1). However, when specifically asked about the wording they use in practice, 82% state that they do not differentiate between emotions and mood in practice. The majority of participants agreed that it is more meaningful to focus on one illustrative term in their psychotherapeutic work to not confuse their patients. One therapist commented: *"[...] when you work with people it doesn't make sense to differentiate"* (P6). Thus, we follow the terminology of the therapists in this paper and use *feelings* as a generic term for emotions and mood.

In line with the approach of focusing on one easily understandable concept (e.g. feelings) to support patients in their psychotherapeutic process, participants further emphasised the importance of responding to individual patients' needs in a flexible manner. Nine therapists elaborated that the specific method that best supports a patient needs to be chosen on an individual basis and may vary as much as using conversations, drawings, diaries, objects, imaginary journeys/guided imagery and many more.

All therapists stressed the importance of **recording** feelings. Even though the majority of therapists mentioned the value of flexibility in interactive technologies when **recording** feelings, seven also imagined utilising **predefined** recording options, using properties like emojis, scales, colours, or labelling words to choose from. However, two therapists stressed not to use intensity scales or graphs, as this could distort the bigger picture of the own well-being and one participant explicitly emphasised not to use smileys: *"They are too vague, an emotion has many layers and is constantly changing"* (P8).

The caution towards **predefined** recording methods is further illustrated by four

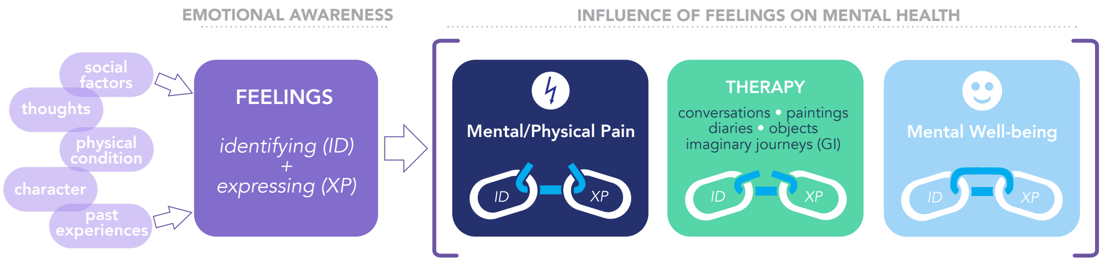


Figure A.1: Schematic conceptualisation of the second theme *Mental Health as Holistic Concept* based on the interviews. By using therapeutic methods patients learn to identify (ID) and express (XP) their feelings, which re-establishes their mental well-being.

participants who pictured an **unrestricted** implementation method, like journaling or being able to create own labels for feelings. Further, five therapists suggested **prompts**, meaning that an app urges the user to answer deeper questions, or that an AI suggests how one could feel given a specific situation.

Mental Health as Holistic Concept.

During our interviews, many participants explained that mental health is a holistic concept. It includes mental, physical and social well-being and is not merely the absence of mental illness. Using the words of one of our participants: *"True healing is about body, mind, and soul"* (P7). Furthermore, therapists explained that thoughts as well as physical conditions influence feelings: *"When I think in a certain way, it affects how I feel. And if I think differently, it may be that my feeling is no longer quite as dramatic"* (P5).

For all therapists, mind, body, and the process of engaging with feelings are directly linked to well-being. Figure A.1, composed of the therapists' descriptions, shows the schematic conceptualisation of the role of ER therapy and the influence of feelings on well-being. One therapist highlighted the value and the challenge of being able to connect with and regulate one's emotions: *"Mental health is when emotions are agile and can be contained. When my feelings are frozen, such as with depression, or if my emotions are overflowing and too much and cannot be tamed, [as for example] with borderline patients or self-harming [patients], then that is because the feelings cannot be regulated"* (P1).

Consistent with a holistic approach towards mental health, therapists emphasised that apps should address feelings, thoughts and physical aspects. For seven therapists, the ideal app should **support** the user by offering **teaching & tips**. One therapist stated: *"It's good to know that I feel this way or that way, but it's also good to know how*

I can feel better, to help people to help themselves" (P6). To achieve this, five therapists suggested that apps could tutor and guide through exercises. Five others imagined apps offering emotional support, e.g. through affirmative quotes. Therapists also expressed the importance to include some psycho-educational elements to educate and to provide background information about chosen symbols or objects in apps. As an example, P1 imagined that a patient chose a wolf in a VE: *"[. . .] and then you could read two or three sentences about it, and then they [the patients] think about it, 'ah, so I took the wolf, then maybe I feel like this and that'. To have the mirroring aspect again"* (P1). For three participants, another important aspect seemed to be a notification option that support the user to not forget thinking about their own well-being during the day.

Many therapists also thought about the supportive feature of **sharing** data with others. Although three therapists discussed the benefits of sharing thoughts and feelings with other patients via some form of social network, opinions deviated between the productive and destructive nature of social networks. However, four participants approved of sharing content with the therapist. In regard to VR, three participants considered recording and documenting sessions meaningful to revisit later, and to share those with therapists to offer them a better glimpse of their imagination. It was stressed, though, that one of the benefits of VR is to use it in the privacy of your own home: *"[. . .] where nobody sees this but me"* (P3).

Offering a Safe Place

Many therapists emphasised that the task of therapy is to support the emotional awareness of the patients by helping to internally *identifying* and externally *expressing* one's feelings, which is in line with related work (sec. A.2.1). This is best highlighted by the following statement: *"Independent of whether it is behavioural therapy, depth psychology, or systemic analysis, it is always about emotions being activated in therapy and this leads to success"* (P9).

By activating emotions and engaging with them, therapy supports patients in processing the past, understanding the present, and developing strategies for the future *"to act appropriately"* (P4). However, therapists stressed that they mostly need to start small. Nearly all, 10 out of 11 participants, elaborated that patients have trouble naming feelings and that therapists spend a lot of time teaching that *"'good', 'bad', and 'I can't get up'"* (P3) are not descriptions of feelings. In figure A.1, this is expressed by becoming emotionally aware of one's feelings.

Consequently, apps should support the user in identifying and reflecting on one's feelings. For instance, many therapists had some form of psycho-educational training to **reflect** in mind, e.g. to explore the causes of experienced feelings. Seven therapists suggested that apps should prompt the user in linking a feeling with a specific situation to increase the awareness of the causes. That being said, identifying and reflecting on one's feelings can only happen in a space where people feel safe. Therapy is, inter alia, about the possibility to live emotions in a way often inappropriate or suppressed in everyday life. 10 therapists emphasise that it is important in therapy to offer a space *"to just exist with the feelings"* (P1). A quote by one therapist captures this notion: *"It is also very important for the person himself to meet his feelings in a visualised way, to hear or see his loneliness. I provide the framework for him to be angry at times (...). That also has something relieving, because it is just allowed in this specific setting"* (P10). Thus, apps should offer a safe environment to express the own feelings. Therapists assessed VR as an opportunity to offer patients such a safe space.

To illustrate, most therapists saw the benefits of VR apps to **relive** a certain experience or environment that is either similar to own memories or to a desired situation. More precisely, seven participants imagined using **predefined** virtual environments (VEs), e.g. exploring different landscapes or having a walk in a park. Thus, they transferred the therapy method of guided imagery to VR. One participant summarised the positive effect of VR for guided imagery: *"When you take body trips [in real therapy], they have an effect on the body as if you were really there, otherwise you wouldn't do that with the patients. I imagine it to be similar when patients use VR for that, that they really experience this imaginary place as if they were there"* (P6).

Furthermore, eight therapists could also fathom a **partly predefined** implementation. Users would be presented with a simple pre-set VE but were able to create their own *happy place* by enriching it through (pre-set) objects, e.g. choosing animals, the weather, other objects, and colours. One contemplated: *"It [pre-set objects] also takes away a bit of individuality, because I preset something. But for patients who find it difficult to visualise things themselves, this could be really helpful because you give them impetus"* (P4).

Apart from that, five participants thought VR should be *"the freer the better"* (P8), which we call an **unrestricted** implementation. They imagined using abstract forms, colours, or creating avatars representing a specific feeling. Two participants could also envision constructing a VE from scratch. They stated that this would help practice visualisation techniques that are also useful in stressful situations in real life: *"I could also imagine that they [patients] would like it, if they were really angry, that they could simulate a really violent thunderstorm so that the weather and the whole environment would adjust to their mood. For some of them, it would be a great help to accept it [their*

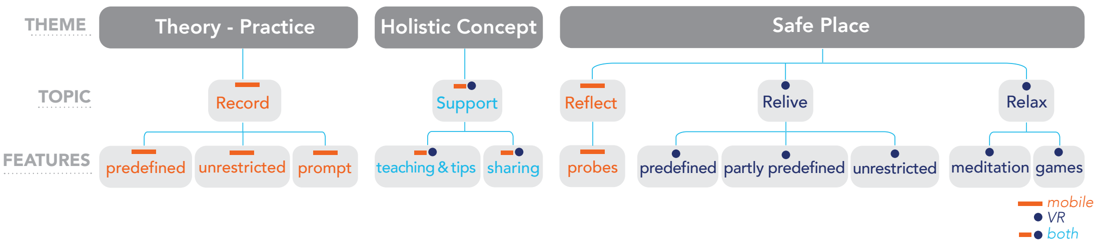


Figure A.2: Themes derived from the interviews, including topics and features that form the basis for mobile (orange), VR (dark blue) and both (light blue) app reviews. Specific properties of each feature, e.g. emojis or graphs, are not listed in this figure.

anger], if they could transform the whole room around them into their feeling" (P3).

However, six participants were of the opinion, that VR should be rather used to experience positive emotions as they were unsure of the risk of getting re-traumatised. Thus, besides supporting reflection and reliving safe environments, to **relax** is a third important aim of such VEs. Nine participants focused on releasing stress and further three mentioned that having fun in the process of experiencing a predefined VE or by creating one themselves could already improve one's mood.

A.4 Mobile and VR App Review

To further explore how autonomous mental health management technologies are currently supporting mental health and well-being (**RQ$_2$**) and to identify possible mismatches between the therapists' recommendations and commercially available apps, we systematically analysed 45 mobile and 15 VR apps that focus on engaging with feelings. We included both mobile and VR apps in our review as users interested in improving their well-being could potentially use them separately or together, since both are available on the consumer market (e.g. in leading app stores). Thus, it is valuable to explore opportunities and limitations of both and how they can complement each other to support autonomous mental health management. Mobile and VR apps were coded using three topics each, which are further divided in several features and properties derived from the interviews (fig. A.2).

A.4.1 Method

Our analysis includes 45 mobile and 15 VR commercial mental health and well-being apps. We inductively coded the features and properties derived from the interview results. Our systematic search process is depicted in figure A.3.

Figure A.3: Systematic 3-step process of searching, filtering and screening of mobile and VR apps, resulting in 45 mobile and 15 VR apps.

Selection criteria

Two authors defined several selection criteria in iterative discussion sessions. We selected mobile apps from the iOS App Store and the Google Play Store and VR apps from three major gaming platforms (Steam, Oculus and Viveport). The final search terms encompassed apps that contained *mood*, *emotion*, *feeling*, *wellbeing*, *well-being*, and *mental health* in either their title or description. We chose these search terms because therapists and patients often use these terms interchangeably (sec. A.3.2), and to take different notation possibilities into account. In addition, we limited the search to the categories of *Health & Fitness*, *Medical* or *Lifestyle*, which are the same for all app stores. We focused on apps that seem to have relevance for users. As a proxy for this, we used the rating count (i.e. the amount of people that wrote reviews) with a threshold of 100 reviews. Unlike the number of downloads, the rating count is available on iOS App and Google Play Store and is thus comparable. As VR apps tend to have fewer reviews overall, the criterion of a minimum rating was not included. We then screened for duplicates.

The systematic review followed a 3-step process for both mobile and VR (fig. A.3). The initial search rendered 6322 mobile and 964 VR apps. They were then filtered based upon exclusion terms, e.g.*fitness fun* (for a full list see supplementary material), resulting in 71 mobile and 332 VR apps (Viveport does not support exclusion). Finally, the apps were screened manually to ensure their relevance, e.g. horror related VR games were excluded. The final body included 45 mobile and 15 VR apps (collected in September 2020).

Coding Process

Based on the interview results, we coded mobile and VR mental health and well-being apps separately (fig. A.2). Two authors initially coded the apps independently. Then, in an iterative process, they discussed the results and coding of features and properties. Any ambiguous case was discussed with the other co-authors. Our final codebook is

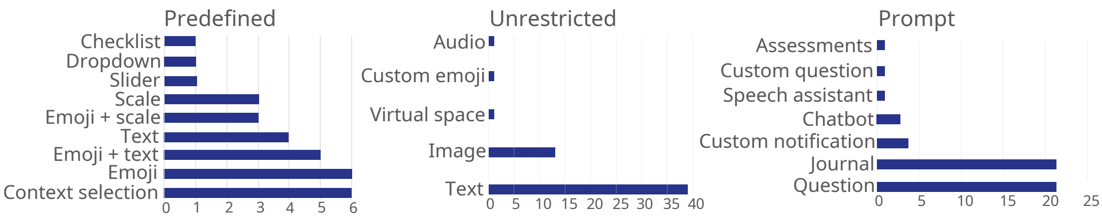


Figure A.4: For the topic of *record* the features were categorized by the type of interaction which ranged from *predefined*, *unrestricted* to *prompt*.

presented in figure A.2.

The mobile apps were analysed in-depth by using them at least three times over the course of a week. The VR apps were played at least once [1].For both, descriptions available on the respective app stores were analysed on the premise of getting insights into important app features that might have been missed while using.

A.4.2 Mobile Apps

Results Mobile Apps

Based on the interviews, we analysed 45 mobile apps focusing on the three topics **record**, **support** and **reflect**, and corresponding features (fig. A.2). For a more fine-grained analysis, we also explored the usage of specific properties such as emojis. For a detailed description, please consult the supplementary material.

In the topic **record**, we investigated the flexibility of recording one's feelings. The results are depicted in figure A.4. For the feature *predefined*, emojis and emojis combined with other properties such as text were used most often. For the feature *unrestricted*, a text recording feature was found in 39 apps, surpassing all other properties. We further examined the usage of *prompts*. Using questions as triggers and journals were the most popular form of prompts, found in 23 apps each. Artificially intelligent chatbots that are able to reply dynamically, thus acting more as a therapist than a static journal, were found in three apps.

Mobile apps also offer **support** by providing *teaching & tips* and *sharing* options. To teach, 21 apps used exercises or tasks, 17 apps a form of tip, advice or guide, and eight apps quotes or affirmations. Regarding *sharing* options, 10 apps utilised community based sharing, e.g. with other app users, and four offered private sharing with friends.

[1] Apart from the App *Prana* [576], which is to date not yet released. Here, we watched demonstration videos and playthroughs on YouTube.

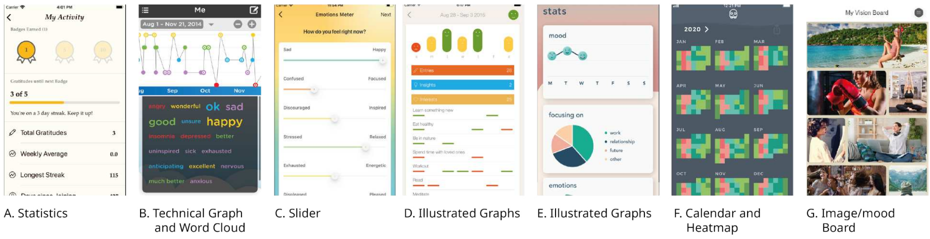


Figure A.5: Examples of *probes* used by apps to **reflect**, ordered with increasing complexity and vividness. Image sources: A [449], B [629], C [564], D [69], E [362], F [356] G [594] .

The topic **reflect** deals with methods of how apps enable the revisiting of the recorded data to support self-reflection. Some examples for *probes* are shown in figure A.5. Five apps used statistics, mainly in the form of listed numbers associated to an activity (fig. A.5A). The most common probe used were graphs. Technical graphs (fig. A.5B) were found in 12, and illustrated graphs, using some form of embellishments such as emojis to further support the presentation of data (fig. A.5D,E), were found in eight apps. Two apps used word clouds, virtual spaces and scores (fig. A.5B). Calendars to prompt reflection, not merely as a form to navigate, were found in nine apps (fig. A.5F). The more visual means such as image collection or mood boards were found in two apps (fig. A.5G). As a meta analysis, apps were further rated according to their assistance to reflect upon reasons and causes of feelings, which is called situation analysis.To determine its use, apps were rated as providing low (raw data is presented without guidance), medium (data is presented in context of other data but without direct suggestions about its meaning), or high (direct suggestions and correlations between feelings and causes are presented) levels of situation analysis support. Forty-three apps were rated low, two apps medium and none high.

Discussion Mobile Apps

We will now discuss the findings in relation to the insights from the interviews. In line with the requirements of therapists in regard to sec. A.3.2, mobile apps offer a wide range of **recording** possibilities, of which emojis are dominating as predefined properties. We want to emphasise that eight apps combine them with further elements like text or scales, probably to support the learning process of identifying feelings, thus teaching ER skills. A similar reason might also relate to the high usage of text. As a predefined property, it provides labels for feelings, which expedite the recording of data so that it can be captured more regularly, and as an unrestricted property as

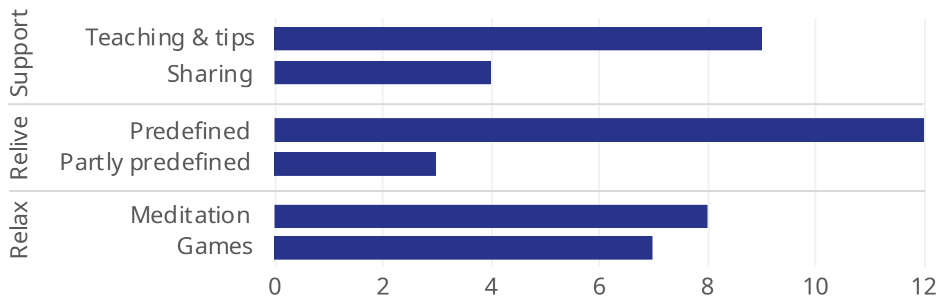


Figure A.6: Graph shows the amount of VR well-being apps fitting to the topics *support*, *relive* and *relax*, and its corresponding features.

prompts, it offers individuality, as wished by nine therapists. However, only three apps offer artificially intelligent chatbots, although five therapists mentioned such prompts specifically because of their benefits to teach ER strategies.

Besides offering tips and guides, ten apps provide **support** via *sharing* data with others, although restricted to other users and friends. Based on the therapists' opinions, we emphasise the potential for using apps as a way to also connect with professionals for remote support, which may increase the development of ER strategies.

Whilst recording will already provide some opportunities for reflection, many apps provide further features to explicitly **reflect**. We identified graphs as the most popular probe. This contrasts the findings from our interviews, where two therapists specifically mentioned not to use graphs. We further identified that only two apps support a medium and none a high level of situation analyses, which was addressed by seven therapists. Although some attempt to support a deeper reflection process (e.g. six apps use a labelled photo of a recent activity for context selection), it appears that most apps present raw data without further guidance on how to reflect upon it.

A.4.3 VR Apps

Results VR Apps

We analysed 15 VR well-being apps focusing on the three topics **support**, **relive**, and **relax** (fig. A.2). For a detailed description, please consult the supplementary material. The results are shown in figure A.6.

Fourteen apps provided some form of **support**. Of those, seven offered *teaching & tips* via tutorials and instructions, such as guided meditation sessions (fig. A.7A,B), and two via in-game information, such as psycho-educational elements and affirmative quotes (fig. A.7C). Four apps also offered *sharing* possibilities, either by presenting information about one's game statistics or opportunities for recording and screenshots. One app has what can be interpreted as a link to professionals, flashing a warning notice and advising professional support if needed [2].

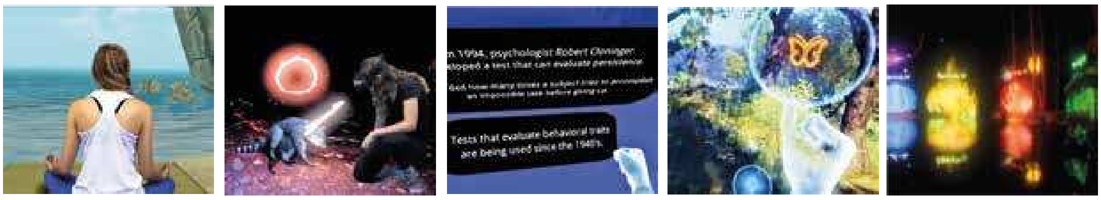
Within the topic **relive**, 12 apps were *predefined*, in which the users are presented with pre-set environments. Users can only choose between different environments or music before they enter an otherwise non-interactable VE. Three apps use a *partly predefined* method, of which two provide some interaction with the VE [157, 201] and one offering possibilities to create new (though preset) objects like trees or command the weather (fig. A.7D). None offered an *unrestricted* environment.

Regarding the topic **relax**, eight apps focus solely on meditation exercises. To distinct further, six focus on meditation through preset VEs (e.g. fig. A.7A), while two [158, 576] added gamification elements to meditation, e.g by reviving animals through relaxing one's respiration (fig. A.7B). Further, seven apps offer relaxation through games for enjoyment such as stone skipping or popping balloons.

Discussion VR Apps

We will now discuss the findings in relation to the insights from the interviews. To **relax** was the most prominent aim for VR well-being apps, mentioned by nine therapists. Eleven VR apps meet this criterion, consolidating both the participants' opinion and findings from research [546, 582, 636]. However, the main focus of the apps is on meditation (six apps of our sample, e.g. fig. A.7 A,B). This was surprising as meditation was not once mentioned by therapists. As an explanation, commercial meditating VR apps seem to target mostly non-professionals and are rated as especially helpful and engaging for beginners [166]. This might reflect (and re-influence) the pre-dominant opinion in society, that an average user automatically equates relaxation with meditation, as previously addressed, e.g. by Lukoff et. al. [333]. This finding highlights the need to better educate users by including psycho-educational elements, as four therapists emphasised. However, only one app included such psycho-educational in-game information (fig. A.7C).

Additionally, therapists emphasised the importance of flexible interactive technologies and the possibility to autonomously *create* a VE. Only one [224] included some form of self-creation (fig. A.7D) by allowing the user to grow trees, have butterflies flying around, and changing the weather in an otherwise pre-set VE. This was unanticipated as creating an own VE is already used quite a lot in non-commercial therapeutic apps [33, 583]. Thus, we propose that commercial VR well-being apps should enhance the interaction possibilities with the VE to allow users an unrestricted interactable VE



A. Meditation as Relaxing Exercise | B. Gamified Meditation | C. In-Game Psycho-Education | D. Partly Predefined with Self-Creation | E. Colour-Themed Emotion Worlds

Figure A.7: Examples of VR well-being apps. Image sources: A [145], B [576], C [2], D [224], E [201].

to build their own imaginary world, as elaborated in sec. A.3.2.

Additionally, 10 therapists stressed that therapy should offer a space for unbiased emotional exploration and expression. This aspect was only mentioned once in regard to VR, which was surprising because VR is considered an efficient medium for artistic expression [90, 292]. Although also switching between virtual settings, e.g. beach and forest, might elicit different feelings, only one app [201] publicly communicates the aim of emotional exploration. It offers coloured emotion worlds to *"discover new emotions"* and to *"explore different kinds of mental states and find your emotional balance"* [201] (fig. A.7E).

Finally, all therapists were sceptical regarding the risks of VR and agreed that digital well-being apps should only be considered as additional tools. Only one app [2] addresses this aspect by adding a note about possible risks. Previous work has shown that meditation, which we found to be the focus in our VR sample, has many potential benefits (e.g. inducing positive emotion [166]). Nevertheless, users should be informed about possibilities and limits of mental health support technology. Thus, based on the recommendations of the therapists we interviewed, we propose that all commercial VR well-being apps should add such a notice.

A.5 Discussion

In this research, we explored current lived therapeutic practice and how commercially available technologies support mental health management. We conducted qualitative interviews with psychotherapists and a systematic mobile and VR app review. We identified several recommendations for digital mental health management **(RQ1)**, including, amongst others, the need for supporting the user in a holistic way and to offer a safe place in which patients can reflect, relive emotions and relax (fig. A.2). Our mobile and VR app review finds that the implementation of such elements varies to a great extent within each medium **(RQ2)**. We use the themes identified in our qualitative analysis as an outline for our discussion.

A.5.1 From Psychological Theory to Lived Practice

Therapists' opinion about a flexible usage in the wording is met by the apps, as has been demonstrated by the hundreds of results when using the search terms *emotions*, *feelings*, *mood*, *mental health* and *well-being*. However, such labelling is also misleading. To illustrate, based on our initial search, we got presented with a multitude of different mobile apps (e.g. apps to regulate ambient lighting, to monitor cannabis usage or a violent VR app shooter game). It seems as if the interchangeable use of these terms found in psychological therapy gets transferred to the field of digital technologies, thus, making it hard for users to immediately find an appropriate app. Further, therapists expressed a desire for a flexible framework that does not limit an individual's expression of emotions, feelings or moods, given that most people have trouble understanding or defining such concepts. We propose that apps could provide definitions of terms, e.g. 'feelings' vs. 'emotions', thus offering skill acquisition, but should also allow users to choose their own wording. We also found that apps seldom offer customisable user interfaces and methods to record their feelings, that can be changed according to the current mood. Effectively, users would need to switch completely to another app in order to individualise their recording experience. However, taking different mobile and VR apps into account, flexibility is quite high: Apps range from being very precise in conveying statistics but being reduced to numbers and graphs (mobile apps), to immersively experiencing feelings but with less information conveyed (VR).

Recommendation 1: Mobile and VR apps for mental health and well-being could allow users to choose which terms they want to use in their respective app (e.g. feelings vs. emotions).

A.5.2 Mental Health as Holistic Concept

Therapists envisioned mental health as a holistic concept, stressing that mental well-being is a conglomerate of thoughts, physical and mental health. Regarding the therapists' wish for psycho-educational information (e.g. how to differentiate feelings from physical reactions), they, inter alia, imagined the usage of worksheets, quizzes and in-game information. Only few apps reflect the holistic view on mental health. We found a clear lack of psycho-educational features in mobile, and only one VR app included them [2]. This holds also true for affirmative quotes, which can strengthen the mindset, which was included in only one VR app [201]. Bakker et al. [34] point out that mobile apps are well positioned to deliver psycho-education by multimedia and audiovisual tools, while [290] highlights the importance of a mind-body-dialogue in VR. Both complement our findings that apps should put more emphasis on teaching and advising mechanisms.

Regarding the physical aspect, it was surprising that although smartphones can easily provide accessible objective data about physical activities like step count [354], only few included such information. One example is *Life Cycle*, which uses Apple Health to import physical activities and sleep data. The developers of the VR app *D.R.I.L.L* [158] were the only ones in our VR examples that acknowledged the physical aspect as part of engaging with one's feelings. Examples such as the iOS Health App [19] and the VR well-being platform DynamixVR, of which D.R.I.L.L.[158] is part of, prove the feasibility of interpreting mental health as a conglomerate of aspects.

Recommendation 2: Mobile and VR apps for mental health and well-being should approach mental health as a holistic concept, including psycho-educational and sportive elements.

A.5.3 Offering a Safe Place

In lived practice, therapists offer a safe space for patients to engage with their feelings, to safely reflect upon emotions, to relive (and relieve of) emotions, and to relax. They also stress the importance of digital apps doing the same. Yet, this was one of the most underdeveloped areas of commercial apps. Our study shows that many mobile well-being apps heavily rely on the feature *record*, but the depth and possibilities to *reflect* differs greatly from app to app. An area that is noticeable missing is how apps can scaffold and guide the reflective process, in other words rather than simply displaying data back to a person, apps could explore approaches that provide more guidance on the reflection process. Bakker et al.[34] recommend that apps should report thoughts and feelings by presenting data in regards to the treatment goal. We argue that apps should broaden this aim to provide more guidance on how to interpret the data (reflection).

In both interview and VR app analysis, the VR approach seems to be less focusing on cognitively *identifying* and *reflecting*, than on the topic of *reliving*. Therapists described it as a learning-by-being method, that a) makes users feel automatically calm by visiting predefined VEs, b) can teach them ER strategies, specifically imaginary journeys, that are useful in stressful situations in real life, c) helps in *expressing* emotions by seeing and feeling visualisation techniques, e.g. by adjusting the outer environment to inner feelings (one therapist gave the example of visually expressing anger by a black thunderstorm), and d) can be a gamified process which can relieve users by having fun in the process of creating an own safe place or by adjusting the outer environment according to inner feelings. Research highlights the potential of VR to offer such playful artistic expression [292], which improve one's well-being [290].

However, VR well-being apps should also offer other methods than the learning-by-being approach, such as learning-by-mirroring, e.g. through an avatar. We further assumed more unrestricted environments based on the high demand for individually fitting safe places. Despite literature suggesting that VR (and mobile apps as well) as new technologies could be used as artistic media to individually design therapeutic environments [90, 237], we found only one app that at least partly allows for adjusting the environment [224].

Recommendation 3: Mobile and VR apps should combine cognitive and affective approaches to mental health management (e.g. probes and artistic expression).

A.5.4 Limitations and Future Work

The interviews revealed interesting distinctions between the envisioned features for mobile and VR well-being apps. Yet, we recognise that the approach used in this paper is prone to certain limitations. As we did not want to influence the participants in any way, we only mentioned the well-known use cases of mood tracking for mobile apps and of anxiety therapy for VR apps. However, as the therapists had very little experience with both mobile and VR well-being apps, we could have used a multiple-choice questionnaire, shown them videos, or have them try out several apps to increase the level of detail with which the therapists answered questions about specific app properties. Future research could identify specific design considerations for mobile and VR apps to make them more attractive for therapists and users. Moreover, future work could take other stakeholders' opinions into account, identifying user and app developer preferences.

A.6 Conclusion

This paper analysed commercially available mobile and VR apps for mental health using lived therapeutic practice as an understanding lens. To that end, we conducted interviews with therapists, developed a coding scheme and analysed 60 mobile and VR apps. We found that there is a mismatch between what therapists envision digital technology to provide and what commercial mobile and VR well-being apps offer. Currently, most mobile and VR well-being apps focus on a specific well-being aspect, cannot be fully customised, lack opportunities for individual expression and should offer more support to users in identifying and reflecting upon their feelings. We hope that our results provide a starting point for future discourse between therapists, scholars and commercial app developers and provide a common grounding and language between different stakeholders.

Acknowledgements

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Part III

DESIGNING the VIRTUAL SPACE

"Those who look outwards are dreaming, those who look inwards are awakening."
– C.G Jung

Transition

Figure T2.1: Visualisation of the Research Questions: RQ2. This figure will be gradually extended in each transition chapter of each part to highlight the main research theme, corresponding to the RQ addressed in the subsequent chapter. This second stage depicts the virtual space with different modalities, highlighted in orange, which are explored in this dissertation in regard to their impact on self-care.

The systematic expert review of consumer VR applications (paper *A - AppSurvey*) highlighted a significant mismatch between therapists' expectations of digital technology and the offerings of commercial VR well-being apps, emphasising the need for deeper exploration in the design space of meaningful VR-based SCT. Key requirements and guidelines outlined in the previous paper shape the direction and design of the publications discussed from here on. Specifically, the previous paper suggests various pathways for improving and enriching the design of VR-based SCT's 'virtual space,' such as making them customisable, diversifying them beyond catering for mindfulness and relaxation, using the space to educate users as well as creating safe spaces that are important for making users comfortable with the self-care application. Part III of this thesis adopts an exploratory approach to investigating tactile, auditory, and visual stimuli. This approach is schematically depicted in Figure T2.1. Below it is detailed how the findings from the previous paper influence the subsequent publications.

First, we identified a lack of customisable options and *unrestricted* virtual environments, although the interviewed therapists emphasised their importance. Further, in that regard, we also want to emphasise the identified lack of opportunities for individual expression. Thus, paper D provides customising options through a toolset in VR that allows users to create a virtual environment fitting their personal needs. It can be used to express emotions through visualisation techniques e.g. by adjusting the environment to inner feelings, as suggested by therapists.

We also found that laypeople find it challenging to discern between the correct terminology to use and, thus, might have a hard time selecting a fitting application for self-care. This highlights the need for a diversification of offers in the consumer market. However, this diversification was not evident in the market, as all VR applications assessed in our review primarily focused on relaxation through meditative activities. This finding is supported by HCI literature, criticising that less focus was placed on exploring self-care practices promoting introspection and cognitive change [459], for self-reflection [555] or for emotion regulation except for exposure therapy [340]. To address these research gaps, this thesis keeps the broader picture in mind, investigating the design space for different well-being beyond meditation. Paper *C - VeatherReflect* caters to self-reflection, and paper *D - MoodWorlds* addresses self-expression. Yet, due to the high number of available consumer applications for mindfulness as found in *A - AppSurvey*, and high interest in mindfulness-based stress reduction research in HCI [601], paper *B - Haptics* still investigates mindfulness exercises, albeit with a focus on facilitating introspection, not meditation. For instance, it supports moving around in the virtual environment, an aspect typically not included in meditation applications.

Further, paper *A - AppSurvey* established a need to consider well-being as a holistic phenomenon, combining educational elements, engaging experiences, physical movement and mental well-being support in self-care applications. As a first step in that regard, paper *C - VeatherReflect* links mental well-being with cognitive education and with physical movement. In more detail, it provides psycho-education regarding personal stress data using qualitative instead of quantitative visualisations, thereby aiming to enhance the understanding of the connection between physical and mental well-being.

Paper *C - VeatherReflect* is further inspired by recent trends in SCT design [405], indicating that an increasing number of SCTs are adopting alternative visualisations of numerical data, in the hope that it deepens self-discovery, promotes informed decisions and increases the amount of insights gathered from health data [189]. In line with this trend in SCT, the goal is to extend beyond generating aesthetically pleasing charts towards generating engagement and enabling users to gain new insights [405]. Consequently, paper *C - VeatherReflect* explores an unexplored method of immersing users into weather scenarios in VR representing their stress levels, with the aim of deepening self-reflection.

Additionally, in paper *A - AppSurvey*, therapists highlighted the importance of creating a safe space as a basic requirement for effective self-care, no matter the exact strategy used in the following self-care practice. As such, we explore in paper *D - MoodWorlds* if and how a VR toolset can be used to create virtual environments that are individually perceived as a safe space.

B Influence of Passive Haptic and Auditory Feedback on Presence and Mindfulness in Virtual Reality Environments

Abstract: Virtual Reality (VR) is increasingly being used to promote mindfulness practice. However, the impact of virtual and multimodal interactive spaces on mindfulness practice and presence is still underexplored. To address this gap, we conducted a mixed-method user study (N=12). We explored the impact of various multimodal feedback, in particular tactile feedback (passive haptic feedback by artificial grass) and auditory feedback (footstep sound) at feet level on both mindfulness and presence. We conducted semi-structured interviews and collected quantitative data through three validated questionnaires (SMS, IPQ, WSPQ). We found a significant effect of passive haptic feedback on presence and mindfulness. Tactile feedback improves the focus on the self, facilitates spatial presence and increases involvement. Auditory feedback did not significantly affect presence or mindfulness. While ambient sound was perceived as beneficial for presence, footstep sound subjectively disrupted both presence and mindfulness. Based on our results, we derive design recommendations for multimodal VR applications supporting mindfulness practice.

Contributions: This paper, exploring the impact of multimodal stimuli on self-awareness, contributes the following. First, a mixed-method design investigating tactile and auditory feedback at feet level. Second, insights regarding the effect of passive haptics and auditory feedback on presence and mindfulness, as well as for self-awareness. Finally, design implications for VR-based SCT that strive to provide meaningful applications for self-care.

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Figure B.1: Participant sits on 2x2m^2 artificial grass floor while conducting a mindfulness task in a virtual nature environment.

B.1 Introduction

Mindfulness practice positively impacts mental well-being and health [638]. It is increasingly becoming a part of our everyday well-being routines. For instance, meditation as one aspect of mindfulness practice was considered the fastest growing trend in the US in 2018 [127]. There is not one set definition for mindfulness and mindfulness practice, partly due to its long history and different mindfulness traditions [121, 333, 149]. However, in contemporary psychology, mindfulness is often defined as a mental faculty of intentionally being aware of the mind, body, and physical environment in present-time [553], while being in a mental state of acceptance [272, 273]. Mindfulness can be trained through varying practices, among others guided mindfulness meditation [272], walking meditation [130] or short-term mindfulness training programs [324]. To illustrate, people practising mindfulness might train to stay focused on a specific object or activity (e.g. respiration, sensory information) [553]) while cultivating a non-judgemental attitude [324].

On the other hand, technology is increasingly used to support mindfulness practice [21]. In 2020, 370 mindfulness-related smartphone apps such as *Calm* or *Headspace* could be downloaded [333], trend increasing. In 2021 mindfulness tutorials such as *Headspace Guide to Meditation* were released on the streaming service Netflix. Furthermore, also Virtual Reality (VR) is increasingly used to practice mindfulness [227, 389]. To support, multimodal VR environments and spaces offer great benefits for mindfulness, increasing positive emotions when conducting mindfulness exercises [513] and fostering relaxation while reducing mind wandering [21].

Nonetheless, with new technologies the ICMI, VR and HCI communities are also facing new challenges. We hypothesise that when multimodal cues differ between VR and reality, especially when visual and auditory cues in VR mismatch from haptic sensations and auditory cues in reality, it might break presence and disturb mindfulness practice. To elaborate, presence describes the subjective feeling of being there in the VE [631], and often successful VR interventions, e.g. VR rehabilitation [117] or empathy enhancement [492], can be traced back to an achievement of high presence. Among others, presence is increased through high realism in the VE [255], which can be achieved through multimodal stimuli [247], e.g. by applying physical laws, environmental sounds, haptic feedback [313] and the correct rendering of walking over virtual grounds [348]. As, by definition, mindful practice increases the awareness of oneself and the surrounding of the present moment [273], low presence through mismatches of visual, tactile and auditory cues could distract while high presence could support attention to body and mind. As an example, use cases of VR are mostly limited to enclosed spaces such as the living room or scientific laboratories, both of which consist of static flooring such as carpet, wood, or linoleum. However, most VR applications use natural settings for relaxation [227, 603], as experiencing nature significantly increases relaxation compared to urban settings [130]. As stepping on hard surfaces in reality feels different and creates other distinct stepping sounds than moving on virtual grass, it creates a mismatch between visual, auditory and haptic cues which can distract users from mindfulness practice.

Although other work has shown that footstep sound [161] and tactile feedback [301, 348] can increase presence, that presence can facilitate mindfulness practice [389, 513], and that immersive and multisensory VR can support presence and mindfulness [21, 389, 513], empirical knowledge of how a mismatch between visual, auditory and haptic cues affects presence and mindfulness is lacking so far [350].

To address this research gap, we explore to what extent multimodal stimuli at feet level affect presence and mindfulness. Multimodal stimuli comprises tactile feedback by passive haptics in the form of (mis-)matching ground (linoleum and artificial grass) and auditory feedback by playing footstep sounds adapted to the material of the ground while walking in VR. This paper contributes the following: (1) a mixed-method within-subject study (N=12), (2) insights regarding the effect of passive haptics and auditory feedback on presence and mindfulness, and (3) a set of implications to inform the design of future VR applications that strive to provide meaningful mindfulness interventions.

B.2 Related Work

Technologies within interactive spaces to support mindfulness practices and well-being are becoming increasingly important in people's well-being routines [21, 529]. Concurrently, popularity of mindfulness practices has grown over the past few years [471, 363, 529]. In the next sections, we will define mindfulness and its benefits for well-being and health. Then, we will discuss the relationship of mindfulness to presence in VR settings, and to multimodal feedback, focusing on tactile and auditory feedback.

B.2.1 Benefits of Mindfulness Practice

Partly due to its long history, a variety of different mindfulness definitions exist [121, 333, 149]. This paper follows a definition rooted in contemporary psychology, in which mindfulness is defined as a mental state of present-moment awareness, thus intentionally focusing on present-time aspects [272]. Following this definition, mindfulness encompasses two components: present-moment awareness, i.e. paying attention to specific physical or bodily objects and/or mental states in the present moment (i.e. *what* experience a person focuses on), and mental attitudes, e.g. curiosity, perceptual sensitivity to stimuli, acceptance of present moment experiences (i.e. *how* a person engages with experiences) [65, 324, 479].

Benefits of mindfulness practice are manifold. For instance, mindfulness increases well-being [91, 524]. Also, mindfulness positively affects mental health as an integral part of holistic health and effective functioning in society [638]. Furthermore, on a cognitive level, mindfulness improves executive attention [7] and enhances creativity [131, 265], which in turn can support flow and presence [635]. Amongst other aspects, mindfulness further positively influences visuo-spatial processing, working memory, and executive functioning [650]. Our study focuses on the question on how to best utilise immersive multimodal features of virtual worlds to enable the most effective mindfulness practice.

B.2.2 Relation of Mindfulness, Immersion and Presence in VR

VR is increasingly used to support mindfulness practice [21]. VR was found to increase relaxation [435, 21], support mindful meditation [167, 389], and reduce mind wandering while preserving attention resources [21]. Seabrook et al. [513] found that mindfulness exercises in VR increase state mindfulness and positive emotions. One reason why VR can successfully be used to foster mindfulness is because it can immerse users by stimulating their perception of sensory, vestibular, proprioceptive, and interoceptive channels [71, 466]. The better VR succeeds, e.g. by addressing multisensory experiences, the greater the user's presence [466].

Both high immersion and high presence benefit mindfulness practice in VR [513]. Presence is the subjective psychological state of being in one place (the VE) while actually physically situated in another (the reality) [631]. High immersion reduces distractions from reality, which favours presence and provides the opportunity to dive into different virtual locations, which benefits mindfulness practice [389]. Further, VR was found to increase relaxation [435, 21], support mindful meditation [167, 389], and reduce mind wandering while preserving attention resources [21]. Seabrook et al. [513] found that mindfulness exercises in VR increase the state of mindfulness and positive emotions.

Also commercial apps using the benefits of VR can offer support for mindfulness practice. As discussed in Wagener et al. [606], most commercial VR apps for mental health do not clearly differentiate between terms such as mental health, well-being, relaxation, meditation and mindfulness, making it almost impossible to clearly differentiate between the terms. Commercially available VR apps offer realistic and calming natural settings, such as beaches [1], lightly wooded meadows [2], and mountainous VEs [3]. Others place the intervention in more abstract space-like environments [4]. Some also include mindful and meditative games that motivate deep breathing [5], repetitive motion [6], and slow body movement [7].

Inspired by these approaches, we endeavour to build an understanding of the interplay of mindfulness and presence within a carefully designed environment. Our aim is to derive insights on how to build multimodal mindfulness spaces in VR to increase the well-being of users.

B.2.3 Relation of Mindfulness with Multimodal Feedback in VR

VR offers potential advantages to support mindfulness practice in multi-sensory VEs [21]. In the following, we will outline examples of related work which illustrate how tactile and auditory feedback can be created in a multimodal VE and how it can potentially foster mindfulness.

[1] e.g. Guided Meditation VR, Ozential, Perfect Beach VR, Zen Zone
[2] e.g. Guided Meditation VR, Mind Labyrinth VR, Nature Treks VR
[3] e.g. Mind Labyrinth VR, Wise Mind VR
[4] e.g. Conscious Existence, Guiding Star VR Meditation, Zen Zone
[5] e.g. Prana, Zen Zone
[6] e.g. Re Mind VR, Wise Mind, Zen Zone
[7] e.g. Guiding Star VR Meditation, Wise Mind

Haptic feedback is created by somatosensory pressure receptors informing users about physical contact with objects [614]. For example, haptic feedback can be created through imitating forces, movement and other sensations felt when touching objects [348]. Such tactile sensations can be provided by active (generated by vibrotactile actuators or motos [398]) or passive haptics [323, 398]. Passive haptic feedback either uses corresponding analogue materials with the same physical properties, e.g. shape and texture [398], or proxy materials mimicking those properties [153]. It has been shown that tactile feedback may increase presence [348] and emotional responses [271, 361]. Furthermore, it can lead to more realistic experiences [589], and in turn it can be perceived as stronger in high-realistic environments [474]. Though active haptic feedback has been shown to increase presence more than passive haptic feedback [301], devices for active haptic feedback are often bulky, heavy and restrictive [301]. To the best of our knowledge, the relevance of tactile feedback for mindfulness practice has not been researched yet. Consequently, our study inquires the impact of passive haptic feedback on mindfulness experiences in VR.

Auditory cues provide important information about the entire environment [281]. For example, ambient sound creates the sense of being surrounded by a spatial scene [309] and facilitates the localisation of objects [309]. Auditory cues such as footstep sound require a controlled setup to superimpose sound with real-time body movement. Possibilities to achieve this include HMD's sensor data [281], VR trackers [250], and microphones [400, 519, 588]. However, all those approaches face challenges, e.g. through occlusion or unintentional noise artefacts. To avoid those, some studies rely on force-sensitive resistors (FSRs) instead. FSRs capture the pressure when the foot touches the ground and a microcontroller communicates this input to the VE. They can be positioned underneath the shoe sole [250], at insoles [355, 530], and at multiple foot areas [355], although the highest pressure is exerted at the heel [530]. Research showed that auditory cues detected by FSRs can increase the users' presence in VR and the awareness of the own body posture [250], and can facilitate mindfulness practice by creating interactive soundscapes, e.g. in meditative walking experiences [130, 500] or in respiration awareness training [440]. Contrarily, improper sounds can easily lead to breaks in presence [250]. Instead of using auditory feedback to inform mindfulness practice, in our paper, we investigate the effects of auditory feedback on mindfulness. To our knowledge, the effect of auditory feedback on mindfulness has not been researched so far.

B.3 Virtual Environment Design

Commercial VR apps that support mindfulness (see section B.2.2) are designed in heterogenous ways. Literature has shown that mindfulness and presence are both influenced by the level of fidelity and the degree of realism of virtual environments [255]. Also, related work has shown how easy both mindfulness and presence can be disturbed [250, 313]. Thus, we took special care with creating our study setting. Consequently, we conducted an exploratory pre-study.

B.3.1 Pre-study

In a between-subjects pre-study with N=20 (9 female, 11 male) with an average-age of 22.9 years (min = 17 years, max = 30 years), we tested our design in regard to presence. Participants either experienced the VE with or without artificial grass as flooring. The participants did not see the artificial grass when entering the lab. After participants finished with the task of picking up apples (for more information see Section B.4.3), they filled out the IPQ [503] to indicate their level of presence. Additionally, their behaviour during the study was analysed to gain further insights [533]. In addition, semi-structured interviews were conducted. Both, the interviews and comments voiced by participants during the study were audio recorded and transcribed. The qualitative data was analysed using thematic analysis [83].

We found no significant effects for the two conditions, calculated with the Wilcoxon rank sum with continuity correction on a .05 confidence level. Presence was above average, scoring above 3 for all IPQ subscales. Our qualitative findings showed that all participants experiencing the grass haptic feedback expressed positive feedback. All participants (N=20) were positively surprised by the flooring, and reported a perceived increase in presence. Some (N=13) also suggested further adjustments of the VE, such as sound and ambient sound.

B.3.2 Final Virtual Environment

Based on the pre-study results, we adjusted the virtual environment and study design. We designed a high fidelity VR scene as realism has a positive influence on presence [255]. In a natural setting, which ameliorates mindfulness and relaxation [130], participants entered the VE in a wooden hut which was equipped with rustic furniture and interactive objects such as plates on a table. When exiting the hut, participants experienced a grassy front yard with an apple tree, which is surrounded by a fence (see Figure B.1). The fence restricted the playable area for the users and visually separated the yard from a meadow on which several animated animals roamed, e.g. rabbits and deer. This whole scene was placed in a mountainous location. Also, the sun was shining bright and, based on inquiries of some pre-study participants, the scene included ambient sound of birds chirping and wind rustling through trees and grass.

B.3.3 Implementation

Passive haptic feedback is provided by a 2x2 m^2 artificial grass flooring. Further, a 2x2 m^2 linoleum flooring simulated the wooden floor of the hut and was used to guarantee a maximum difference of flooring. Artificial grass was placed at the virtual door sill so that the ground noticeably changes when stepping out of the hut. As described in Section B.2.3, a reliable solution to detect foot step sound is a force sensitive resistor (FSR) attached to a foot. We used an ESP82662 microcontroller unit (MCU) with the NodeMCU firmware, which is powered by a lithium-ion battery (3.7V) and a connected FSR. The electronic parts are protected by a plastic box case and strapped to the ankles (see Figure B.2). The pressure sensors are sellotaped to the heel and additionally fixed with a disposable sock. When the heel hits the floor, the sensors are activated and send a foot identifier to differentiate between left and right foot, and a pressure value to a TCP server in Unity. Footstep sound is only played when the pressure value surfaces a certain threshold to mitigate false signals. As suggested by Hoppe et al. [250], the

Figure B.2: Attachment of the sensor at the heel and MCU at the ankle.

virtual location of the sound source is placed at the user's feet to create a more realistic atmosphere. Further, grass stepping sounds, taken from Fesliyan Studios[1], randomly varied between seven samples to generate a more realistic and diversified soundscape. As a further change based on results of the pre-study, taking off the HMD to fill out

1 https://www.fesliyanstudios.com/royalty-free-sound-effects-download/footsteps-on-grass-284

questionnaires accounts as a break in presence [11, 513]. Thus, to ease participation [441] and to mitigate those breaks that can be disengaging for mindfulness practice [513], we embedded the questionnaires into VR based on the concept by Alexandrovsky et al.[1] [11].

B.4 User Study

The effect of passive haptics in combination with footstep sound was evaluated in a user study. The study was designed as a within-subject experiment with two independent variables with two factor levels each: tactile feedback (grass G and no grass NG) and auditory feedback (with footstep sound F and without footstep sound NF). The order of conditions was counterbalanced and randomised (Latin square) to minimise sequencing effects.

B.4.1 Participants

We used our extended social network and snowball sampling to recruit participants. Twelve participants (2 female, 10 male) that have not been part of the pre-study with an average age of 25.5 years ($min = 18$, $max = 30$ years) participated in the study on a voluntary basis without receiving remuneration. Two participants had never tried out VR in their lives, nine had used it once or occasionally, one several times a week. Three had specified to work with VR.

B.4.2 Data Collection

We gathered quantitative and qualitative data from the participants to understand the potential effect of passive haptic and audio feedback on mindfulness and presence. Quantitative data was collected from three validated questionnaires (SMS, IPQ and WSPQ). Further, we gained qualitative insights through interviews.

Measures

The following dependent variables were measured for both conditions: **Mindfulness** was measured by the state mindfulness scale (SMS) [573]. In contrast to other self-report measures (i.e. state-Mindful Attention Awareness Scale [91] and Toronto Mindfulness Scale [310]), SMS reflects mindfulness as the objects of mindful awareness (i.e. what experience a person focuses on, including physical sensations and mental events) and

[1] 1https://github.com/alexandrovsky/VRestionnaires

the qualities of mindful awareness (i.e. how a person attends to experience, including perceptual sensitivity to stimuli, deliberate attention, willingness to feel, curiosity) [573, 479]. The 21-items, rated on a 5-point Likert scale, are split into two subscales that measure bodily sensations in the SMS-body subscale (maximal possible scoring = 24) and attention to and awareness of mental events (e.g. emotions, patterns of thought) in the SMS-mind subscale (maximal possible scoring = 60). Higher scores reflect higher levels of state mindfulness. A summation of the subscales results in the total score of mindfulness.

Presence was measured with two scales. First, we used the igroup presence questionnaire (IPQ) [503]. The IPQ is split into four subscales, general presence (sense of being there), involvement (attention devoted to the VE), experienced realism (subjective experience of realism in the VE), and spatial presence (feeling physically present in the VE). Further, we used the Witmer and Singer Presence Questionnaire (WSPQ) [632] for presence measurements. Although criticised, among others due to its length [532] and not differentiating enough in their question setting [510], it is the most often used presence measurement in literature [11, 441]. It is divided into four sub-scales: involvement (inclusion of the user), interface quality (resolution of the VE), sensory fidelity (visual, haptic and auditory elements), and adaption/immersion (interaction possibilities and adaptability of the VE).

Interview Protocol

We conducted semi-structured interviews that lasted on average 22.22 min, asking about general user experience, their most memorable experiences in the study and what they focused on. All audio recordings were transcribed verbatim and imported into Dovetail [1]. Two authors both coded two interviews using open coding. Then, a coding tree was established through iterative discussion. The remaining transcripts were coded individually by one author using the coding tree. A final discussion session between two authors was conducted to identify emerging themes using thematic analysis [83]. The interview protocol can be found in the supplementary material.

B.4.3 Procedure & Tasks

After welcoming and briefing, participants themselves (due to hygienic restrictions) fixed the sensors under their heel with sellotape and a pair of try-on socks, attached the prototype to their ankles (see Figure B.2), and made sure that sitting was comfortable.

[1] https://dovetailapp.com/

They put on the HMD (HTC Vive Pro) with a wireless adapter to offer a cable-free solution. Throughout the study they used one controller in their dominant hand.

As an introduction to the study, participants envisioned being on vacation in a cabin in the mountains, and that they wished to feed some animals by collecting the respective amount of apples. The apples laid on the grass in the front yard and participants were asked to put them in a basket, which was located inside the hut. This counting task ensures that participants encounter different ground surfaces with their hands and feet when switching between different flooring material. Afterwards, participants took a seat on the ground in the front yard to perform a 3-minutes guided relaxation exercise based on the mindfulness app *Headspace*[1] that was played via the HMD headphones. Participants were free to choose if they wanted to close their eyes and keep the controller in their hand. Detailed information can be found in the supplementary material. Thereafter, participants filled out the in-VR questionnaires (SMS, IPQ, WSPQ) inside the hut. This guaranteed space for the experimenter to change the ground surface for each condition (i.e. preparing or removing grass) and to reduce breaks in presence for the participants. This procedure was repeated in total four times. Post-study, participants were asked for their preferred condition and post-test interviews were conducted remotely.

B.5 Results

Based on the user study, we gathered qualitative insights from the interviews and quantitative results from the questionnaires. Our findings will be presented in this section.

B.5.1 Qualitative Results

Based on our qualitative inquiry, four themes were derived from the data: *Iterative Immersion*, *Multi-Sensory Experience*, *Simplicity* and *(Virtual) Reality*. Our findings are described below and illustrated with excerpts from the interviews.

Iterative Immersion

The first theme derived from our data focuses on how relaxation and presence were enhanced through an iterative process. The theme consists of two codes: *Iterative Entry* and *Iterative Procedure*.

[1] https://www.headspace.com/

Participants enjoyed being gradually immersed in the VE. As a first step, they put on the HMD and were located inside the virtual wooden hut. In a second step the participants themselves opened the door and entered the natural scene. This two-step process made them more relaxed and they felt that they were able to behave more freely. Participants described similar experiences when stopping the virtual experience and re-entering reality after the study was done. As a last step, they filled out the in-VR questionnaires inside the hut, which, first, again changes the environment back to a closed space more similar to the room in reality. Second, the task of filling out questionnaires was encountered as a tedious task, detached from the actual VR experience, therefore providing a transition between the virtual experience and the lab environment. While some participants reported benefits of the iterative procedure and sequence within the study, some participants assessed the duration of the study as tedious, too long or boring. The following statement illustrates how the iterative process allowed participants to feel safe in the VE and being able to foresee that nothing dramatically changes:

> It took me a few iterations to really get into this world. But from round to round, this meditation or relaxation exercise contributed more and more to the fact that the immersion got better. (P3)

Multi-Sensory Experience

The second theme encompasses the influences of different modalities on presence and mindfulness. We split this theme into four codes according to computer-human modalities in HCI [64]: *Vision*, *Tactition*, *Audition*, and *Uncommon Modalities*.

Participants emphasised that *vision* - more precisely being in an aesthetically pleasing environment, thus allowing for immersion - is the most important modality. Further, they also described that the beauty of the environment, especially the brightness, colours, light reflexes and being in nature, supported them in their relaxation.

The second code, *tactition* encompasses findings about the relationship of haptic sensation with presence and mindfulness. All participants enjoyed the feeling of grass. The material properties (warm, soft) was praised especially in contrast to the linoleum flooring (cold, hard), and made the setting more comfortable and, effectively, more relaxing. We also found that haptic feedback enriches mindfulness. Participants reported that by stroking the grass, they concentrated more on their own body and felt their focus shift to the self. P5 clarifies:

> And I think that's why I found it so pleasant to really caress this grass with

my hands, because it helped me to focus a bit on myself and my body. (P5)

The third code, *audition*, evolves around effects of various audio outputs. First, participants positively commented on the ambient sound. All participants explained that the sound atmosphere was convincing (except when the loop ended), increased realism and presence, and that it facilitated relaxation during the mindfulness task. Some participants mentioned that they closed their eyes to concentrate on the soundscape, and that they could not differentiate between reality and VR anymore.

Not as conclusive were the results for the stepping sound. Although some reported an increase in presence, because it complemented the overall experience, or that it did not matter because walking on grass would only make a soft sound in reality as well, most participants concentrated too much on technical issues to accept this modality. They criticised that the volume was too loud, the tone too unconvincing, the appearance too temporally displaced, which all in all led to breaks in presence. Some participants also mentioned, that the sound made them aware of their walking habits, which further decreased their presence.

Moreover, participants reflected on the benefits of adding *uncommon modalities*. Some participants noted that the more senses were involved the better because it reflects reality. They desired olfactory elements such as smelling mown grass, addressed thermoception by feeling the sun's warmth, and thought about adding ventilators to simulate a breeze. Those would further enhance the realism of the VE, increase presence, and, hence, participants assume it would improve positive affect and mindfulness. However, some participants also decided to filter out overlapping unconvincing modalities that lacked in authenticity so that their presence and mindfulness is not disturbed.

Simplicity

The third theme, *simplicity*, focuses on the design of the virtual experience. First, participants aimed to discover limits of VR, either by inventing games such as stacking apples to test physical laws or by checking how well vision and tactition are aligned, as well as how well objects in VR resembled their real counterparts. Second, participants were curious and attempted to reduce insecurities. Thereby, the simplicity and iterations of the study itself helped because it increased the familiarity of the VE. These experiences resulted in higher presence and increased relaxation, because participants were sure that nothing new or scary, like a jump scare, would happen to them. One explained:

It was a nice, simple process. And the clearer it became, the more relaxing

> it was. (P3)

Some participants decided to savour the moment by closing their eyes. In contrast, others felt that the virtual experience is ‘too precious to close the eyes’ or that they had to keep their eyes open for the sake of the study.

As a last aspect regarding the theme simplicity, the instructions providing guidance during the mindfulness task were not memorable. Although participants could remember the calming sound of the voice, they were often undecided of its gender and reported, that after the first introduction of the task, they stopped listening to the voice in the following iterations to instead fully concentrate on relaxing.

From Reality to VR to Reality

The last theme describes the loop of how participants were reminded of reality while being in VR, and in turn how their virtual experience influenced their lives outside of the virtual experience. Some participants mentioned that it felt somewhat like a break or a short vacation from their everyday lives, contrasting the busy daily schedule they normally experience. On the other hand, some were reminded of real experiences they made as they connected their memories with the virtual experience based on the similarities of what they felt:

> During the study I sometimes felt as if I were in this park [in the neighbourhood]. Maybe a little bit away from it [other people], it was quiet, it was nice, I could hear birds, nature around me, so to speak. Then I just thought back a bit to that feeling. (P4)

We also found that some imagined using the VR app again in the future to feel the same form of relaxation. Further, some reported a lasting effect of relaxation even after the study had ended. Some participants were even inspired by their experience during the study to change their lifestyles in reality accordingly. They had identified their need for and benefits of mindfulness due to the study:

> I actually did that afterwards, I (...) went to the park and sat there, but not on the ground, on the bench and really, I think I just sat there for almost an hour or so. That really helped, I will definitely take that with me for the future, that [mindfulness practice] is beneficial. (P11)

Table B.1: Mean value and standard deviation for the SMS subscales *Body*, *Mind* and *Total*, the IPQ subscales *General*, *Involvement*, *Experienced Realism*, and *Spatial Presence*, and the WSPQ subscales *Involvement*, *Interface Quality*, *Sensory Fidelity* and *Adaptation/Immersion*, calculated for each condition.

	SMS						IPQ								WSPQ							
	Body		Mind		Total		Gen.		Inv.		Real.		Spat.		Inv.		Int.Q.		Sens.Fid.		Adapt.	
Variables	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
G:FS	17.09	3.53	40.27	8.05	57.36	10.30	4.91	0.7	4.20	1.17	3.73	0.69	5.04	0.80	58.82	8.47	5.36	4.11	27.55	3.93	41.45	5.07
G:NF	17.36	3.14	43.55	6.56	60.91	9.10	4.73	0.90	4.27	1.29	3.55	1.23	4.48	0.57	55.64	9.99	5.27	4.36	27.09	3.91	40.00	4.17
NG:FS	14.91	3.45	41.36	6.31	56.27	9.00	4.09	0.94	3.57	1.26	3.36	0.88	4.64	0.57	53.36	9.95	5.64	3.75	25.55	5.66	38.73	5.61
NG:NFS	14.91	3.70	38.36	6.68	53.27	9.97	4.18	0.87	3.52	1.37	3.25	0.54	4.64	0.62	54.45	11.12	5.73	4.56	22.73	5.93	37.55	4.27
G	17.23	3.26	41.91	7.36	59.14	9.66	4.82	0.80	4.24	1.20	3.64	0.98	4.94	0.69	57.23	9.19	5.32	4.13	27.32	3.83	40.73	4.59
NG	14.91	3.49	39.86	6.53	54.77	9.40	4.14	0.89	3.55	1.28	3.31	0.71	4.64	0.58	53.91	10.31	5.68	4.08	24.14	5.84	38.14	4.90
FS	16.00	3.59	40.82	7.08	56.82	9.45	4.50	0.91	3.89	1.23	3.55	0.79	4.84	0.71	56.09	9.44	5.50	3.84	26.55	4.87	40.09	5.40
NFS	16.14	3.58	40.95	6.99	57.09	10.10	4.45	0.91	3.90	1.35	3.40	0.94	4.74	0.59	55.05	10.33	5.50	4.36	24.91	5.39	38.77	4.31

B.5.2 Quantitative Results

A two-way repeated measures ANOVA was conducted to examine the effect of Tactile Feedback and Auditory Feedback on mindfulness and presence. Results are structured according to the questionnaire answers SMS, IPQ and WSPQ of N=11 participants (one was excluded due to technical difficulties). Visual inspection of our data in combination with using the Shapiro–Wilk test showed that our data is not normally distributed. Accordingly, we applied the Aligned Rank Transformation (ART). Descriptive statistics of all results are presented in Table B.1. We refer to the different conditions combining Tactile Feedback and Auditory Feedback as $G : F$ (grass + footsteps), $G : NF$ (grass + no footsteps), $NG : F$ (no grass + footsteps), $NG : NF$ (no grass + no footsteps).

Participants were also asked to state their most liked condition after the study. Five participants preferred condition $G : NF$, four $G : F$, and two enjoyed both conditions with grass, no matter if step sound was included or not. One could not decide.

Mindfulness

A two-way repeated measures ANOVA was conducted to examine the effect of Tactile Feedback and Auditory Feedback on mindfulness. The test showed a significant effect of Tactile Feedback on the SMS subscale *Body* F(1,30)=13.043, p=.001. Further, we found a significant two-way interaction effect of $G : FS$ regarding the subscale *Mind* F(1,30)=8.14, p=.008. Post-hoc pairwise comparison using Tukey-adjusted p-values showed a significant difference between $G : NFS$ and $NG : NFS$ (p=.014). Additionally, we found a significant effect of Tactile Feedback on the

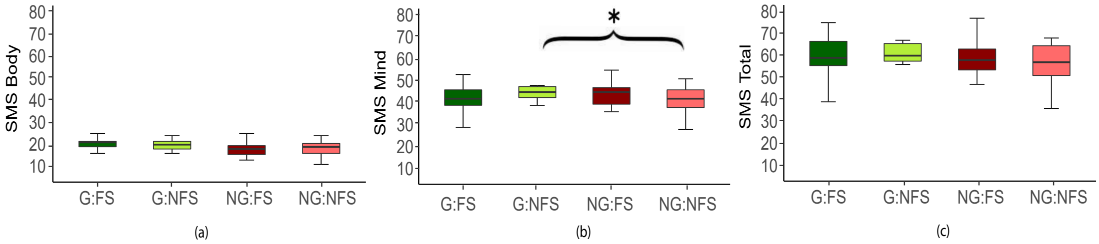

Figure B.3: Mean value of SMS subscales (a) Body, (b) Mind and (c) Total for the four conditions. Conditions where Tactile Feedback is involved are represented in green, conditions where Auditory Feedback is involved are shown in red. Post-hoc significance is indicated (* p< .05).

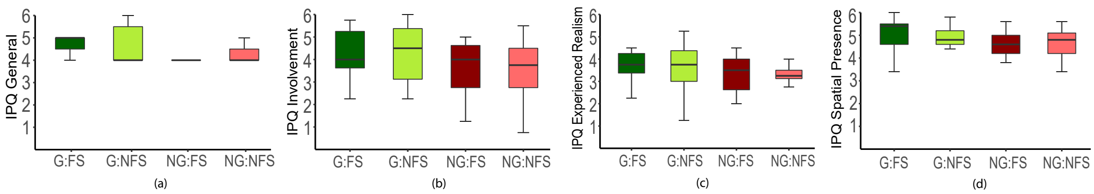

Figure B.4: Mean value of IPQ subscales (a) General, (b) Involvement, (c) Experienced Realism and (d) Spatial Presence for the four conditions. Conditions where Tactile Feedback is involved are represented in green, conditions where Auditory Feedback is involved are shown in red.

SMS subscale *Total* F(1,30)=7.986, p=.008. The corresponding boxplot is presented in Figure B.3.

Presence: IPQ and WSPQ

Additionally, the two-way repeated measures ANOVA was conducted to examine the effect of Tactile Feedback and Auditory Feedback on presence. The ANOVA showed a significant effect of Tactile Feedback on all IPQ subscales, namely *General* F(1,30)=13.19, p=.001, *Involvement* F(1,30)=7.56, p=.01, *Experienced Realism* F(1,30)=4.372, p=.045, and *Spatial Presence* F(1,30)=9.995, p=.004. The results are visualised in Figure B.4.

Regarding the WSPQ questionnaire, the test showed a significant effect of Tactile Feedback on the subscale *Sensory Fidelity* F(1,30)=17.264, p=.0002 and of Auditory Feedback on *Sensory Fidelity* as well F(1,30)=7.054, p<.013. We further found a significant effect of Tactile Feedback on *Adaption/Immersion* F(1,30)=7.981, p<.008. Our findings are visualised in Figure B.5.

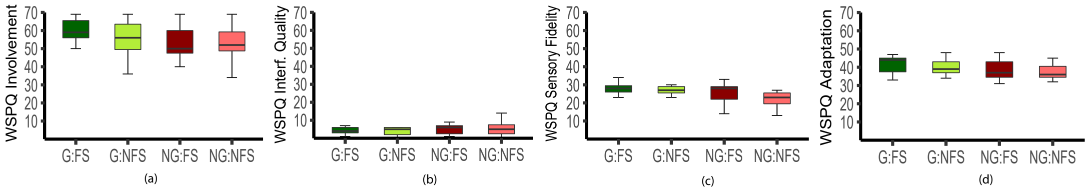

Figure B.5: Mean value of WSPQ subscales (a) Involvement, (b) Interface Quality, (c) Sensory Fidelity and (d) Adaption/Immersion for the four conditions. Conditions where Tactile Feedback is involved are represented in green, conditions where Auditory Feedback is involved are shown in red.

B.6 Design Recommendations for VR Mindfulness Practice

In this work we endeavoured to understand how multimodal stimuli at feet level influence presence and mindfulness. In this section we reflect on our findings and, based on those, outline specific design recommendations for VR applications that strive to support mindfulness practice. We back our qualitative results with findings from our quantitative data. Then, we discuss limitations of our approach and opportunities for future work.

B.6.1 Iteration for Need Fulfilment

One key finding of our study was the importance of a stepwise entry and exit to facilitate the process of immersion. We provided this by offering an intermediate step between reality (lab environment) and the virtual nature experience in form of a closed virtual space, a wooden hut. We then empowered the user to decide for themselves when they feel ready to enter the described natural scene in which mindfulness is practiced. We hypothesise that this allows for autonomy, one of the universal psychological needs motivating people [483]. Participants also expressed needing time to adjust to reality again after being immersed in VR, because reorientation after high presence takes time [510]. In line with our findings, scholars and VR programmers could help with this transition phase.

Further, we found that an iterative procedure helps the process of immersion. Repetition was perceived as relaxing, and a certain duration is needed to experience presence. Although we cannot derive the minimum duration from our data, it should be clearly communicated to users when they have seen all facets of the experience and nothing else will happen to reduce uncertainty.

Recommendation 1: Virtual environments for mindfulness practice should provide a gradual entry and exit process. Iterative experiences and repetition can be helpful in fulfilling psychological needs (autonomy, competence, relatedness) and reducing anxiety.

B.6.2 Aesthetically Pleasing But Simple VEs

In our study, we explored the influence of different modalities. We addressed vision (high realism and fidelity), tactition (passive haptics) and audition (ambient and footstep sound). On a general note, we found that participants reacted to visual, tactile and auditive mismatches quite heterogeneously. Some participants felt that the more senses were addressed, the better the overall experience. Other participants filtered out aspects that disturbed them, while some experienced mismatches as complete breaks in presence.

Significant results of all the IPQ subscales in respect to TACTILE FEEDBACK and of the WSPQ sub-scales *Sensory Fidelity* ($p < .0002$) and *Adaption/Immersion* ($p = .008$) show the importance for high-quality VEs for presence. We want to especially highlight the results of the sub-scale *Experienced Realism* ($p = .045$), which shows that including tactile feedback increases the perceived realism of the VE. Thus, our results reconfirm the findings of related work (e.g. [589]).

On top of that, our qualitative data showed that for some participants relaxation was enhanced by an aesthetically pleasing virtual experience. Based on that, and as we additionally know that high-realistic visual stimuli in a VE can influence how vibrotactile stimulus is perceived [474], we assume that a pleasing surrounding might also enhance the perception of passive haptic stimulus. Thus, we recommend creating a beautiful environment and a pleasant atmosphere. To do so, we suggest placing importance on the following entities, in accordance with our results and related work: high realism of objects [255], natural setting [130, 190, 603], bright colours and light [108].

Although studies regarding meditation in VR have shown that offering visual cues provide focus and help users to feel more present [188], we found that providing too much visual and auditive feedback can even decrease mindfulness. For example, moving animals can distract users from focusing on themselves. Our findings also showed that the simpler the VE, the faster people familiarise themselves with their surroundings. This ties back to the recommendation of offering an iterative procedure to familiarise oneself with every part of the surroundings. It is in line with previous work, showing that the less mentally demanding a task is, the more participants focus on the most minor details [468].

Moreover, some participants reported that they decided against closing their eyes, although it might have helped with their mindfulness exercises because they feared missing out on some of the visual experience. As VR has been proven beneficial for meditation even with closed eyes [167, 389], we hypothesise this was due to our rich VE. Thus, if the surrounding is visually pleasing but simple enough, this would empower users to choose if they want to keep their eyes open or closed. On another note, the voice guiding the mindfulness exercise was mostly ignored or completely blanked out after some time. In this regard, we suggest the premise, 'introduction above implementation', which means that initial guidance benefits mindfulness, but afterwards, it can be perceived as a disruptive factor.

Recommendation 2: Virtual environments for mindfulness practice designed in aesthetically pleasing but simple ways may improve sensory fidelity, involvement, and subjectively experienced relaxation.

B.6.3 Passive Haptic Feedback

The majority of participants enjoyed the haptic experience. As indicated by the preferred conditions, those with grass were rated better overall, while footstep sound had less influence on the selection. During the apple-picking task, participants commented on being able to feel the seam between grass and wooden floor when entering and leaving the hut, i.e. when the visually perceived ground also changed. Our results show that, during the mindfulness task, the haptic experience (e.g. feeling the grass) became more important, increasing presence. Results of the IPQ support this impression, as its sub-scales show that tactile feedback independent of footstep sound has a significant effect on perceived presence, physically feeling present in the VE, and attention dedicated to the VE. Our data suggest several reasons for this development. First, our study setup was reduced to sitting or laying down during the mindfulness exercise, with no other task than to be mindful and relax. Removing distractions (i.e. no counting and manipulation of objects) shifted the focus to other entities such as the ground. Second, as known from the sensory homunculus, which is based on numerous studies conducted on the human brain by Penfield and Boldrey [425], higher sensory processing capacity is dedicated to the hands and fingers compared to the feet. As most participants reported touching the grass with their hands only during the mindfulness exercise, the stimulus would be higher during that part of the study. Further, participants wore socks and try-on-socks on top to attach the sensor. Thus their feet were less exposed to the ground. One could have increased haptic feedback intensity during this task by removing the socks altogether, however, due to hygienic standards, this was impossible in our setup. Third, this development might be due to successful mindfulness practice. By being more mindful, participants focused on what their bodies felt by consciously directing their attention. Thus, we hypothesise that mindfulness positively correlates with haptics.

However, we also found evidence that the other way is true as well: the haptic experience enriches mindfulness practice, thus the other way around. In contrast to previous assumptions, stroking the grass does not increase the focus on the VE but on the self. Participants reported that it helped them to focus and that feeling the grass supported them in feeling and being aware of themselves. This assumption is supported by significant findings of the SMS. Its sub-scale *Body* shows a significant main effect for TACTILE FEEDBACK ($p = .001$), which shows that passive haptics significantly supported participants in perceiving physical sensations and to perceive themselves. Further, *Mind* showed a significant interaction effect between $G : NF$ and $NG : NF$. This further highlights the importance of tactile feedback for calming the mind. Thus, even a small item or object offering passive haptic feedback is potentially more beneficial than no haptic feedback at all. On that note, we also assume that material properties made a difference in mindfulness. Our results suggest that the grass' warmth and cosiness, in contrast to the cold and hard linoleum flooring, made a difference. However, a matching representation of the visual display and the haptic experience was essential for presence, and generally considered equally important by participants. One should test, though, how consistent textures must be to be convincing in VR. This is in line with work from Degraen et al. [153], investigating substitution possibilities for textures in VR.

Recommendation 3: Virtual environments for mindfulness practice should incorporate passive haptic feedback that matches virtual visual experiences.

B.6.4 Unobtrusive Ambient Sound Without Footstep Sound

Besides vision and tactition, audition was the third modality that we specifically addressed in our study. Participants agreed that ambient sound increased presence and relaxation. This is reflected by the significant WSPQ sub-scale sensory fidelity, which includes auditive aspects (p=0.023), although this sub-scale does not differentiate between effects of visual, auditive and haptic elements. Looking at our qualitative data, the effect of audition on mindfulness is not as homogeneous, though. For some, ambient sound was one factor creating a comprehensive experience, a nice atmosphere, that facilitated mindfulness practice. Others reported that they struggled with remaining focused on themselves because they felt their mind wander due to environmental sounds.

Further, auditive feedback in form of footstep sound does neither increase nor decrease presence and mindfulness. This is evidenced by results of the SMS, IPQ and WSPQ. The only exception is the WSPQ sub-scale *Sensory Fidelity* ($p = .013$). Here, it is shown that footstep sound positively impacts the perceived responsiveness of VR. Although the comparison to other subscales supports the conclusion that TACTILE FEEDBACK is the decisive factor, we cannot fully deduce that footstep sound never contributes to presence and mindfulness. However, stepsound was not the decisive factor when rating the preferred condition, and qualitative and quantitative data showed that footstep sound on grass compared to footstep sound on wooden flooring is perceived as less relevant for presence. This might be because sounds are naturally more subdued on grass due to grass' natural material properties. Because also the walking habits changed due to wearing sensors, we conclude that footstep sound measured from ESP sensors used on grassy ground should not be added. This might change, however, if used on different flooring material and in a different setting, e.g. when sneaking [250] or when being in an urban setting [500].

Recommendation 4: Virtual environments for mindfulness practice should include unobtrusive ambient sound that matches the overall setting.

B.6.5 Limitations

As a limitation, we acknowledge our small sample size (N=12), although it still reflects the standard in HCI research [102]. However, our results are in line with prior works highlighting the benefit of haptic feedback for presence [348] and emotional responses [271, 361]. Thus, we extend those findings to mindfulness practice. Still, more research is needed to re-assess our assumptions due to the limitation of sample size and of investigating only the passive haptic feedback of grass and linoleum. Additionally, our study design offered a lot of freedom for the participant, i.e. the choice to hold the one controller in their hands vs. feeling the grass as well as opening vs. closing the eyes, which may have affected our results. However, we believe that the benefits of guaranteeing autonomy as a psychological need [483] enabled us to derive more in-depth insights that inform future design, as can be seen e.g. in design recommendation 1 (see Section B.6.1). Further, nine participants did not have any knowledge of mindfulness, three had minor knowledge from single teaching sessions or reading about it. Thus, our findings could change when repeated with mindful experts.

B.7 Conclusion

In this paper, we explored the impact of tactile (passive haptics through grass ground) and auditory (footstep sounds) feedback on presence and mindfulness. Quantitative and qualitative results of a user study (N=12) showed that tactile feedback significantly increases presence and supports mindfulness practice by improving the focus on the self. Based on our data, we derived five design recommendations for VR apps supporting mindfulness practice. We found that the study design should focus on iterations to support psychological need fulfilment. Also, VEs should be designed in an aesthetically pleasing way but still be simple enough to not distract from mindfulness exercises. Finally, passive haptic feedback and unobtrusive ambient sound can be beneficial for facilitating mindfulness and presence in VEs.

Based on our findings, we identify opportunities for future work. Besides involving mindfulness experts, it will be fascinating to investigate the relationship of less common modalities [64], especially olfaction and thermoception, and their interplay with presence and mindfulness. Though participants assumed a positive relation between such modalities and mindfulness, adding them could also contradict the derived theme of simplicity. As a starting point, we refer to the overview by Hürst et al. [253], as well as work by Maggioni et al. [341] for olfactory, Sheehan et al. [525] for thermoceptory, and Obrist [407] for gustatory implementation possibilities for VR. We hope that this paper will inspire further inquiry into how the interplay of different modalities in VR can support mindfulness practice and eventually increases the well-being of users.

Acknowledgements

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C VeatherReflect: Employing Weather as Qualitative Representation of Stress Data in Virtual Reality

Abstract: While personal trackers can collect a vast amount of information about their users, the representation of such data has remained unchanged, with bar charts being the most dominant. However, to build systems that facilitate reflection and support well-being, it is crucial to explore alternative ways of representation. Thus, we designed VeatherReflect, a VR application that uses weather metaphors to illustrate tracker stress scores, aiming to encourage users to reflect on their stress data. In a pre-study, we mapped stress scores to weather states. We then compared VeatherReflect with a standard visualisation of stress data presented in VR. VeatherReflect increased participant engagement with personal data and stress awareness. Participants reported reflective insights for stress-reducing behaviour. We contribute findings on how virtual weather as a metaphor for stress can support reflection. We discuss design recommendations for VR applications aiming to facilitate a deeper understanding of complex personal data through engaging qualitative experiences.

Contributions: This paper, exploring the impact of qualitative representations in form of VR weather on self-reflection and self-awareness, contributes the following. First, the design and implementation of VeatherReflect— a virtual environment with the aim to support reflection by representing stress levels using weather as a metaphor. Second, a mixed-method user study to evaluate VeatherReflect. Finally, design implications for VR-based SCT aiming to facilitate a deeper understanding of complex personal data using qualitative means to design engaging experiences.

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Figure C.1: VeatherReflect is a VR application that visualises personal tracker stress scores using weather metaphors. The user stands on a platform in space. A semicircle presents a two-hour time frame. Floating videos represent stress levels and can be selected to immerse oneself in the represented weather scenario (sun, snow, rain, thunderstorm).

C.1 Introduction

In 2020, the American Psychological Association proclaimed a national mental health crisis due to a significant increase of stress levels across the USA [23]. They report that stress can negatively affect sleeping and eating patterns as well as social and intimate relationships. Further, the report states that stress can lead to being emotionally unstable and experiencing symptoms of depression and burnout. Thus, it is increasingly important to care about one's mental health and well-being. While there are many approaches and applications for self-care, e.g. promoting stress reduction through breathing adaptation [560, 598, 545, 645], an important first step is to get an overview of and start reflecting on one's stress levels. The primary way in which current technologies can support that process is stress tracking with fitness trackers and smartwatches, which became increasingly popular in recent years [382]. Yet, research shows that motivation to use smartwatches decreases over time due to various reasons [134]. For example, users feel as if smartwatches cannot provide effective in-the-moment stress interventions while, when interpreting stress data in retrospect, they often lack knowledge of the underlying technological mechanisms regarding the measurement of stress [163]. This can lead to increasing disinterest to engage with one's data [163]. Further, research in personal informatics indicates that current standard representations for data, such as bar charts and graphs, are unlikely to effectively foster engagement and reflection [61, 397, 251, 43]. To build systems that effectively and lastingly support users in reflecting on their data, we need to study alternative ways to represent personal tracker measures such as stress levels. Thus, there is a necessity to explore alternative forms of data representation in personal informatics to facilitate reflection.

Concurrently, an increasing amount of research shows that Virtual Reality (VR) may be an effective and immersive approach to present personal data and foster reflection. For example, Yoo et al. [644] visualised physical exercises and daily step data in an interactive VR dashboard. However, the system visualised the data both in VR and on a mobile phone in a similar way (i.e. using bar charts). This example illustrates the unused potential for VR to offer immersive personal data representations that go beyond classic fitness tracker visualisations such as bar charts. The potential of VR for stress reduction and relaxation has been explored extensively [290, 582, 636, 546, 443]. Yet, research in representing personal tracking data such as stress data in new way to support reflection by using the unique affordances of VR needs further attention. We hypothesise VR might foster deeper interest and reflection through offering a new perspective on personal data.

The range of experiences that VR provides is larger than what desktop or mobile systems offers. For instance, VR can offer unique forms of data representation through using qualitative, immersive and more abstract forms of data representations. In this paper, we introduce weather as a novel qualitative data representation for stress tracking data. Weather can influence perceived happiness [305, 133], stress [52], and certain weather types are associated with mental health characteristics [572, 366]. Furthermore, albeit not scientifically proven, people associate similar weather scenarios with emotions and states of being relaxed (sunshine) vs danger (hail, thunderstorm). Thus, weather might offer a valuable qualitative alternative to represent stress data and support reflection.

To that end, we designed VeatherReflect—a VR application that supports reflection on personal tracker stress scores using weather as qualitative means of data representation. In a pre-study ($N = 100$), we asked participants to map weather scenarios to a variety of different stress levels. The design of VeatherReflect was informed by those results. We then conducted a user study ($N = 20$) to inquire user engagement and level of reflection with their personal stress data using VeatherReflect and a standard bar chart visualisation of stress data, also presented in VR. We found that VeatherReflect increased stress awareness and led to more reflective insights for stress-reducing behaviour. It significantly increased immersion, mindfulness and user engagement with personal data.

This paper contributes the following: (1) the design and implementation of VeatherReflect—a virtual environment with the aim to support reflection through representing stress levels using weather as a metaphor; (2) a mixed-method user study to evaluate VeatherReflect; and (3) design recommendations for VR applications that aim to facilitate a deeper understanding of complex personal data using qualitative means to design engaging experiences.

C.2 Related Work

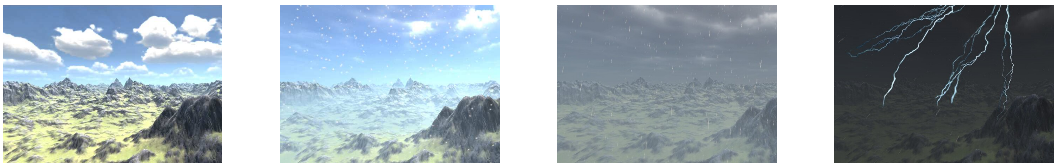
In this section, we first discuss previous work on reflection in HCI to contextualise our work. We then describe the relationship between emotions, health and weather to illustrate the reasons behind choosing weather as a metaphor for qualitative data representations of stress. Finally, we outline how VR can be used to foster reflection.

C.2.1 Reflection in HCI

The HCI field invested considerable effort in building an understanding of reflection, as it can support life changes [554], offer more self-insight [48], and benefit health and well-being [92, 337, 539].

Recent advancements in technology have led to widespread use of commercial tracking devices (e.g. fitness trackers), that are equipped with more and more sensors and offer an ever-increasing level of accuracy. Such devices enable users to collect previously hidden information about themselves and by reflecting on personal data, a user can notice patterns and trends, which can in turn lead to more knowledge about oneself [184]. However, such systems have been critiqued in the past as they often do not actively encourage reflection [124, 296]. As noted by Baumer [48], personal tracking devices often carry an implicit assumption that by showing a user visualisations of their past data for the purpose of reflection, that reflection will automatically occur. Yet, this conflicts with reflection theories that emphasise the importance of encouraging reflection, as it often does not occur automatically [539].

There are various strategies that can be used to encourage reflection, as shown by Bentvelzen et al. [61]. Through a structured literature review and analysis of mobile applications for reflection, they propose a taxonomy consisting of eleven design resources and 74 design patterns. However, while there are many strategies available to support reflection, the majority of commercial fitness trackers apply just one strategy i.e., depicting personal data as bar charts in a mobile app. To build systems that help users



(a) *No stress* was mapped to *sunny* weather.

(b) *Low stress* was mapped to *snow*

(c) *Medium stress* was mapped to *heavy rain*

(d) *High stress* was mapped to *thunderstorm*

Figure C.2: In the pre-study, participants mapped pictures of seven weather scenarios to four stress levels. This figure depicts the findings of the most often selected weather scenarios for each stress level, which were then used as qualitative representation of stress in the main study.

reflect on their data and thereby effectively support well-being, there is a need to study alternative strategies to represent personal tracker measures.

This need is further emphasised by work by Ding et al. [163]. They conducted a study with fitness tracker users who tracked their stress. They found that participants largely did not engage with stress data and tracking did not result in an increased understanding of daily stress, but often led to confusion. There was a mismatch between the physiological stress measured by the device and their personal conceptualisation of stress. These results indicate that the potential for stress tracking to improve well-being is underexplored and alternative ways of reflecting on and engaging with stress tracking data are required to unlock its possible benefits. Our work addresses this gap by exploring alternative ways for supporting reflection on stress data through exploring stress data metaphors presented in VR.

C.2.2 Influence of Weather on (Mental) Health

Although the relationship between weather and emotions, mood and (mental) health is not as strong as generally assumed [320, 154, 252, 226], health and well-being can be influenced by weather. For example, less sunshine can increase stress [52], and amplify or trigger seasonal affective disorders [572, 366], while intensity and direction of wind can influence the level of energy and fear [77]. Along similar lines, cognitive performance decreases with rising temperature [617]. Further, Yu et al. [646] used machine-learning to predict future self-reports of users regarding their well-being, including their stress level partly based on weather data. In their study, weather was found to be strongly associated with well-being labels. Regarding physical health, headaches and joint pain can increase with higher temperature [316], although a connection of arthritis with weather cannot be finally confirmed [541]. Additionally, numerous weather metaphors are used to express emotional states [656], e.g. connecting thunder with negative emotions and sun with optimism or joy. Such common associations of weather are also used in design to encode emotional information, e.g. linking anger to thunderstorms and joy to a clear blue sky [566].

On another note, weather associations presented in VR have also been explored to support (mental) health. For instance, building on notions that VR elicits thermal perceptions [118], virtual environments have been used to facilitate pain reduction, e.g., immersing patients with severe burns in snowy environments (e.g. [430]). Weather can be also used as a means of improving the user experience in VR. For example, realistic weather in VR can lead to an increase of presence [42], can enhance or reduce motion sickness depending on the weather type [9], or can be used to convey meanings as part of VR story telling [470].

These works highlight the common associations between weather conditions and (mental) health, including emotional responses to them, and highlight the potential of using weather as qualitative metaphor for emotional and health-related content. Yet, its association to stress is unverified and will be addressed in our pre-study. This paper focuses on weather metaphors in VR and how they might foster reflection. Thus, it is situated outside of a clinical context. Instead, we use weather as qualitative representation of real-life stress data in VR and explore if and how such representations can support reflection.

C.2.3 Supporting Reflection with Virtual Reality

Many VR applications strive to offer stress management interventions [546], mostly through providing gamified approaches for stress reduction. For example, a variety of systems have been designed to adapt to one's breathing thereby supporting relaxation. [545, 560, 598, 645]. While mirroring real-time stress reactions to users can facilitate reflection-in-action [490], such systems do not provide feedback on one's stress level in retrospect. Users have to get to know themselves to realise beforehand, without the system's help, that they may potentially experience stress and need stress treatment. Reflection-on-action can assist in this process. To support reflection-on-action, there is a need to research how stress data can be visualised using the unique affordances of VR which we will address in this paper.

However, most VR applications utilise reflection as means to learn another concept, for example linking it with empathy skills (e.g. [555]), learning (e.g. [304]), or training (e.g. [653]). Some also found that their interactive system facilitated reflection, although it was designed with another purpose in mind, such as autonomous emotional expression [609]. While Jian and Ahmadpour [266] have built a model to understand how reflection should be supported in VR based on reviews of twelve VR applications, they neither focus on personal informatics nor on specific design approaches that facilitate reflection, such as weather.

There have been a few studies studies that demonstrate the connections between personal informatics, virtual reality (VR), and reflection. Two notable examples are studies conducted by Egan et al. [177] and Yoo et al. [644]. Egan et al. [177] introduced health data such as heart rate data as a reliable way to measure the quality of a virtual environment (VE), while Yoo et al. [644] developed a VR dashboard that offers users a reflective overview of their personal sports data, such as step count. Building on these previous studies, our work aims to extend and combine these approaches. Specifically, we focus on designing for reflection and creating engaging visualisations of complex personal data gathered by smartwatches, all within a VR environment.

C.3 Design

Although previous studies found (perceived) connections between weather and emotions (see. Section C.2.2), little research has linked weather to stress levels. Hence, there is a need to analyse how different weather scenarios relate to different stress levels. To that end, we first conducted a pre-study to study how participants map weather scenarios to different stress levels. We further examined reasons behind those choices by asking participants to describe a situation they imagined when thinking about a specific stress level.

C.3.1 Pre-Study: The Interplay Between Weather and Stress

We conducted a within-subjects study utilising a card-sorting task. We asked participants to assign weather conditions to stress levels. Weather conditions were chosen based on common weather types [408] and adapted according to the availability and visualisation possibilities for VR [1]. Thus, we ended up with the following seven weather conditions: Sun with Rainbow, Sun, Fog, Light Snow, Heavy Snow, Heavy Rain, Thunderstorm. Stress levels were informed by common representations of stress levels used by Garmin and Apple smartwatches: No stress = 0–25%, low stress = 26–50%, medium

[1] To represent those weather scenarios in VR, we used the VR package *Enviro - Sky and Weather* in the main study. Some weather types, such as wind/storm and frost, are hard to depict in photos and in VEs, which is why we decided against them.

stress = 51–75% and high stress = 76–100%. Thus, participants mapped seven weather states to four stress levels. For each of the stress levels (no stress, low stress, medium stress and high stress), participants further described a situation they had in mind when imagining feeling this level of stress. We chose this approach to understand participants' reasoning behind the mapping, and, effectively, to gather more in-depth insights that might inform the design of VeatherReflect.

Participants

One hundred participants ($N = 100$) took part in the online study (55 male, 42 female, 2 other, 1 non-binary) with an average-age of 29.75 years (min = 18 years, max = 74 years). Country of residence encompassed 24 different countries. The study took 6,55 minutes on average.

Findings

The results of the pre-study are shown in Figure C.3. *No stress* was mainly associated with *sunny* (42 times), *low stress* with *light snow* (31 times), *medium stress* with *heavy rain* (30 times), and *high stress* with a *thunderstorm* (46 times).

Further, we investigated why those weather scenarios were chosen through categorising the reported situations depicting each stress level. A detailed overview of this analysis is included in the supplementary material. *High stress* was primarily associated with feeling time pressure due to upcoming exams or deadlines (53 times). *Medium stress* was experienced mostly at work (27 times) and in public spaces (14 times), e.g. when talking to strangers or waiting in queues. A *low stress* level was mainly associated with being at home (12 times), and among friends, family and pets (10 times). *No stress* was associated with being on vacation (21 times), relaxation (24 times) and good weather (17 times).

Design Implications for VeatherReflect

Based on our pre-study, we identified a clear trend regarding the association of designated weather scenarios with designated stress levels. These insights serve as inspiration for the design of VeatherReflect. Based on the results of the pre-study, we mapped *no stress* to *sunny*, *low stress* to *light snow*, *medium stress* to *heavy rain*, and *high stress* to *thunderstorm*, as depicted inFigure C.2. Consequently, these weather conditions were chosen to visualise the stress levels in our main study.

Yet, we found some interesting outliers in our data, which show that a certain level of individual interpretation needs to be taken into account. To give an example, *no or low stress* were sometimes mapped to thunderstorm or heavy rain. Those participants explained, that they - as music lovers - imagined listening to loud music or thought about positive sparks "similar to lightning" within a relationship. In some other cases, *high stress* was mapped to sun, which was a decision informed by this year's drought.

Moreover, participants often mentioned that the sound of the weather has a big impact on their perception of weather. For instance, listening to a light rain or snowfall is soothing, while thunder makes them afraid. Accordingly, we decided to add sound effects to VeatherReflect as well. While this adds another modality, we are interested in researching the effects of a cohesive weather scenario utilising a variety of modalities VR has to offer. We hypothesise that the experience of an immersive weather metaphor in a virtual environment can support reflection on stress data. Hence, based on the insights of our pre-study and the aim of this paper, we opted to add sound to the overall experience. For a more detailed discussion of this aspect, see Section C.6.2. Sun was accompanied by birds' chirping, snow by the sound of light wind, rain by the sound of drops falling on the ground, and thunderstorm by loud rolling thunder.

C.3.2 Final Prototype

The design considerations derived from the pre-study (see Section C.3.1) informed the design of VeatherReflect. The aim of the system is to support users in reflecting on their stress data. To that end, VeatherReflect strives to immerse users in weather conditions that match prior measured stress levels. The relative times of the two hours of measured stress data was placed in a half circle around the user. This represents the x-axis of a standard visualisation of graphs in Garmin smartwatches. Each 15 min segment of the graph (for more information, see Section C.4.1) is mapped to one weather scenario. If participants did not experience any stress (*no stress*) during that time interval, this was represented by *sunny* weather, *low stress* by *light snow*, *medium stress* by *heavy rain* and *high stress* by being immersed in a *thunderstorm*. These weather conditions are showcased via a floating pre-view video depicting a short clip of that weather scenario, e.g. where it is snowing. Peaks, i.e. deviations from the general common stress level in the time interval (for more information see Section C.4.1), were also depicted via floating pre-view videos that were placed at the correct time in the semicircle and placed a bit higher to make them stand out more. Apart from that, the virtual environment consisted only of a barren-looking rectangular plane in outer space. We did not offer any terrain or landscape as this could unconsciously affect the user—a thunderstorm might

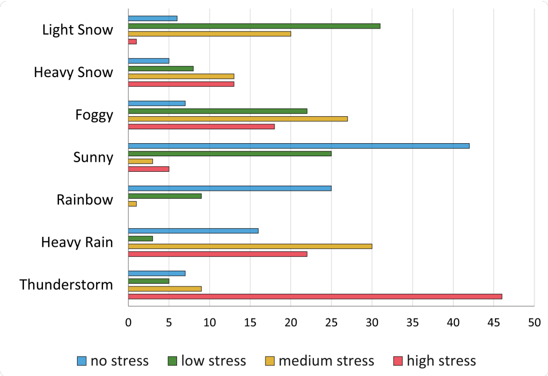


Figure C.3: Results of the pre-study. Seven weather scenarios were mapped to four stress levels (no stress, low stress, medium stress, high stress).

feel different when standing on a mountain than next to a lake. As skybox, we chose a space environment (see Figure C.1 as reference). First, this backdrop is often used in prior research (e.g. [609, 611]) as it is non-distracting, mostly dark, and the backdrop highlights changes in the surrounding, such as added colour or weather. Second, stars and the slightly pink coloured milky way provide enough light to not influence users' mood in a negative way [609, 611]. An exemplary setup of VeatherReflect is shown in Figure C.4.

By stepping closer to the floating video previews, participants could select the depicted weather condition by pressing the controller's trigger button. Upon selection, participants activate that weather scenario, e.g. the cloud cover changes, and they see and hear the rain. To provide as little distraction to the feeling of being surrounded by each weather scenario, the timeline of the semi-circle with the attached other weather scenarios disappeared (see Figure C.4). Everything else, such as the barren-looking rectangular field in outer space remained unchanged. Schematically, this is depicted in Figure C.1. In order to return, participants selected a small pre-view picture of the semi-circle starting scene which is placed on a column in the centre of the stage behind the user.

C.4 Evaluation

We conducted a user-study to evaluate VeatherReflect and compare it with the baseline 2D-Plot. The baseline presents participants with a standard visualisation of stress levels using bar charts in VR. Consequently, we conducted a mixed-method within-subject study with two conditions. The order of the conditions was counterbalanced and randomised.

We decided to compare VeatherReflect to a 2D graph in VR as we endeavoured to investigate if and how an immersive, qualitative representation of stress data in VR can support reflection on stress indicators compared to the standard representation of stress data used in consumer products. An alternative that we considered but rejected was using graphs provided on a smartwatch or another mobile or desktop device. We decided to not compare a stress data representation on a mobile or desktop device to an experience in VR. Presenting data on a mobile device cannot immerse users as VR can, thus potentially adding confounding variables. Also, due to the novelty effect of VR, users might rate any experience as better just because it is in VR. Thus, we opted to translate the 2D graph to VR, hence keeping the same mode of presentation while still providing the same visualisation (i.e. a bar chart) as on a smartwatch.

Consequently, both conditions are experienced in VR and share a similar-looking environment of a barren-looking rectangular field in outer space. Regarding the stress data visualisation, currently commercially available consumer products display stress data differently. For instance, smartwatches from Apple present stress levels in circular bar charts, while wearables from Fitbit and Garmin additionally provide bar charts over time. Yet, in both representation forms, it remains unclear in which time intervals stress is measured. To disambiguate, we chose to visualise more granular level using a continuous graph. Thus, we present the users with stress measurements taken during an activity related to stress and relaxation, e.g. Yoga. Stress levels during the exercise are then presented as bar charts. Time is then as a relative factor, counting from $0:00:00$ upwards from the start of the the activity. Time is presented on the x-axis, and stress levels on the y-axis of the graph. For added ecological validity, we use a colouring scheme based on a consumer-grade product, the Garmin Connect App. Garmin colour codes the stress levels in the following manner: *no stress* is colour-coded in blue, all the other stress levels uniformly in orange.

C.4.1 Conditions

We conducted a within-subjects study with two conditions. The baseline C0 is called 2D-Plot, and condition C1 VeatherReflect. Based on prior considerations as elaborated above, 2D-Plot was also set in VR. Here, participants experienced their tracker stress scores in form of a graph, based on two hours of recorded stress data. This graph visually remains close to the actual data from smartwatches, but its data is prior processed to keep both conditions as comparable as possible. Details about the data preparation can be found in Section C.4.2. This graph is employed as material

(a) Condition 2D-Plot. An aggregated graph of a participant's stress data is shown in VR.

(b) Condition VeatherReflect. Participant's stress level is visualised by weather scenarios.

Figure C.4: Representation of both conditions experienced in VR with the same data as basis. Within the two hours, the participant encountered two spikes, which were added to the eight bars or weather scenarios.

of a virtual plane in VR. The plane, sized 2m in width and 1m in height, was placed approximately on eye level of the participants in a distance of 2m. Thus, the bar chart can be seen in whole without moving the head, and participants can also go up to certain segments and have a closer look. On average, participants spend 00:02:20 minutes (SD = .034) with this condition.

Condition C1, VeatherReflect, is based on the same pre-processed stress scores measured by a smartwatch as condition 2D-Plot. In contrast, here participants' tracker stress scores are represented in form of four types of weather conditions. The design of VeatherReflect is explained in detail in Section C.3.2. On average, participants spend $00:05:56$ minutes ($SD = .116$) in that condition.

C.4.2 Data Preparation

In our study, we recorded two hours of stress data with a Garmin smartwatch (also see Section C.4.6). We used a two-hour recording period to balance regarding gathering conclusive stress data (that is granular enough to show spikes in stress) while minimising participant burden. However, to further investigate stress patterns over time, future studies could adopt a longitudinal design with stress data collected at regular intervals throughout the day. The data points of the two-hour recording were then split in eight segments of fifteen minutes each. Each segment is assigned with the average of its stress values (e.g. when the majority of bars show a low stress level - between 26–50% - then the whole segment will be depicted as having a low stress level). As this somewhat evens out the data, up to four peaks per participant were additionally displayed. Peaks are defined as the strongest deviations from the computed average, e.g. a peak of high stress in a segment of low stress. Peaks were extracted together with the specific time interval they apply to and also averaged. As an example, in a 15min segment of low stress (26–50%), we identified 7min of high stress, split up into three bars with a height of 78%, 80% and 91%. These bars will be depicted as one peak with the calculated average height of 83%. The time interval of each peak is shown on top. X- and y-axis as well as the colour-coding were adopted from the original bar chart taken from Garmin smartwatches. Based on our data processing, we obtained graphs similar to Figure C.4.

C.4.3 Data Collection

Quantitative data was collected from four questionnaires (UES-SF, TSRI, SMS, IPQ-s) which the participants completed after experiencing each condition. Further, we gained qualitative insights through post-test interviews.

Measures

The following dependent variables were measured for both conditions:

User Engagement can be used to measure the quality of the user experience, and the participants' ability to engage and sustain engagement in digital environments [417]. As reflection often requires encouragement [48, 539] and, thus, active involvement from the user, we explore if users engage differently in the two conditions. It was measured with the User Engagement Scale-SF [417]. This 12-item scale, answered on a 5-point-Likert scale is divided into four subscales: *Aesthetic Appeal (AE)*, *Focused Attention (FA)*, *Perceived Usability (PU)*, *Reward Factor (RW)*. All items can be summed and divided by twelve to calculate an overall engagement score.

Reflection that an interactive system can evoke was measured utilising the Technology-Supported Reflection Inventory (TSRI), as proposed by Bentvelzen et al. [59]. The TSRI supports understanding the qualities of an interactive technology which supports reflection, and evaluates how effectively such a system supports reflection. Participants answer nine items on a 7-point-Likert scale. They are categorised in three dimensions, *Insight*, *Exploration* and *Comparison*.

Mindfulness practice has been shown to positively correlate with reflection, through opening up headspace which facilitates reflection [269, 404], and by being focused on the present moment [68]. This can enable awareness. Mindfulness was also found to be a positive contributing factor when reflecting on biosignals [327]. Consequently, if a system measurably increases mindfulness, the probability for reflective practice potentially increases as well. Thus, we also measure mindfulness, using the state mindfulness scale (SMS) [573]. SMS reflects mindfulness as the objects of mindful awareness (i.e. what experience a person focuses on, including physical sensations and mental events) and the qualities of mindful awareness (i.e. how a person attends to experience, including perceptual sensitivity to stimuli, deliberate attention, willingness to feel, curiosity) [573, 479]. The 21 items, rated on a 5-point Likert scale, are divided into two subscales that measure bodily sensations (SMS-body, $max = 24$) and attention to and awareness of mental events such as emotions and patterns of thought (SMS-mind, $max = 60$). Higher scores reflect higher levels of state mindfulness. A sum of the subscales results in the total score of mindfulness.

Presence, defined as the sense of being there in the VE [536], can be linked to reflection as well, as present-moment attention can facilitate reflection processes [68]. Presence was measured using the Igroup Presence Questionnaire (IPQ) [503]. The IPQ is a 14-item scale answered on a 7-point-Likert scale. It is divided into four subscales: general presence (sense of being there), involvement (attention devoted to the VE), experienced realism (subjective experience of realism in the VE), and spatial presence (feeling physically present in the VE).

C.4.4 Interview Protocol

We conducted semi-structured interviews that lasted 14 minutes on average. All audio recordings were transcribed verbatim and imported into dovetail software. Two authors coded three interviews using open coding. Next, a coding tree was established through iterative discussion. The remaining transcripts were coded individually by one author using the coding tree. A final discussion session between two authors was conducted to identify emerging themes applying thematic analysis [83]. Within the interview, we asked about differences between the visualisations, focusing on exploration, understanding, engagement and insights that participants could gain. The interview protocol can be found in the supplementary material.

C.4.5 Participants

We used our extended social network and snowball sampling to recruit participants. In total, $N = 20$ participants (9 females, 11 males) took part in the study ($M = 27.26$ years, $min : 20$ years, $max : 35$ years). They received 20€ as remuneration. Twelve of the participants identified as German, two as Russian, two as Indian, and one each as Italian, Greek, Bangladeshi, and Chinese. Thirteen participants did not own a smartwatch, three owned a Fitbit, two an Apple watch, one a Xiaomi band and one a Mi fit band. If used, they mainly tracked sleep data and step counts, only two reported checking stress, albeit on an irregular basis. Four participants had never tried out VR before, five tried VR once or twice in their lives, seven experienced VR several times a year, one used VR several times a month, and two several times a week.

C.4.6 Study Procedure

Participants were asked to wear either a Garmin Venu sq or a Garmin Vivoactive 4 for at least two hours during their daily routine. To enable granular stress tracking (see Section C.4.1), we started a Yoga activity for these two hours. Our study represents an initial step towards understanding the potential of qualitative data representations in VR to foster reflection. Within the next 24 hours, the participants would take part in the second phase of the study, experiencing two different approaches to represent personal stress data in VR.

For this second part of the study, the participants gave consent, and completed demographics, SRIS and iPAQ-s questionnaires. Afterwards, the experimenter explained the procedure, emphasising that in each condition the participants will experience different forms of visualisations of their stress data that they can freely explore, thus without having a specific task. Before experiencing the VeatherReflect condition, participants were additionally informed how to use the controller to enter weather scenes. They were informed that weather scenarios will be used to represent their stress data, but were not instructed about which weather scenarios was mapped to which stress level beforehand. Screen and audio were recorded, in case that participants started describing their experience in line with a thinking-aloud method. After each condition, participants filled out the UES-SF, TSRI and IPQ questionnaires. Post-test, the experimenter conducted a semi-structured interview. All participants were also informed that they could stop the sessions at any time without giving a reason and without any negative consequences.

C.5 Results

Based on the evaluation, we gathered quantitative results from the questionnaires as well as qualitative insights from the interviews. Our findings will be presented in this section.

C.5.1 Quantitative Results

Our quantitative results comparing 2D-Plot and VeatherReflect in regard to user engagement, mindfulness, reflection and presence are presented in this section. A data set of one participant had to be excluded from the calculations. Specifics about the calculations can also be found in the supplementary material.

User Engagement (UES-SF)

We used a paired t-test to investigate the effect of VeatherReflect on the UES-SF and all its subscales. In regard to *Aesthetic Appeal (AE)*, we found a significant effect, $t(18) = 4.07$, $p < .01$. We further found a significant effect of VeatherReflect on the UES-SF subscale *Focused Attention (FA)*, $t(18) = 7.1$, $p < .001$. We used a paired t-test to investigate the effect of VeatherReflect on the UES-SF subscale *Reward Factor (RW)*. We found a significant effect, $t(18) = 3.00$, $p = .04$. However, we did not find a significant effect of VeatherReflect on *Perceived Usability (PU)*, $t(18) = 1.2$, $p = .25$. Finally, we used a paired t-test to investigate the effect of VeatherReflect on the UES-SF *Total (TOT)*. We found a significant effect, $t(18) = 4.9$, $p < .001$. All p-values were corrected using Bonferroni correction. The significant results are illustrated in Figure C.5.

Mindfulness (SMS)

We used a paired t-test to investigate the effect of VeatherReflect on the SMS subscale *SMS-Mind*. We found a significant effect, $t(18) = 2.97$, $p = .03$. We also found a significant effect of VeatherReflect on the SMS subscale *SMS-Body* when using a paired t-test. We found a significant effect, $t(18) = 3.12$, $p = .02$. We used a paired t-test to investigate the effect of VeatherReflect on the total SMS score *SMS-TOT*. We found a significant effect, $t(18) = 3.23$, $p = .02$. The results are shown in Figure C.6. All p-values were corrected using Bonferroni correction.

Reflection (TSRI)

To measure reflection quantitatively, we used a non-parametric measure as recommended by Bentvelzen et al. [59]. Thus, we used the Wilcoxon paired rank sum test to measure the level of reflection. For the subscale *Comparison*, we did not find any significant differences, $V(18) = 76.5$, $p = .41$. In regard to the subscale *Exploration*, we also did not find any significance, $V(18) = 39$, $p = .72$. Similar results were found for the subscale *Insight*, $V(18) = 25.5$, $p = .87$. All p-values were corrected using Bonferroni correction.

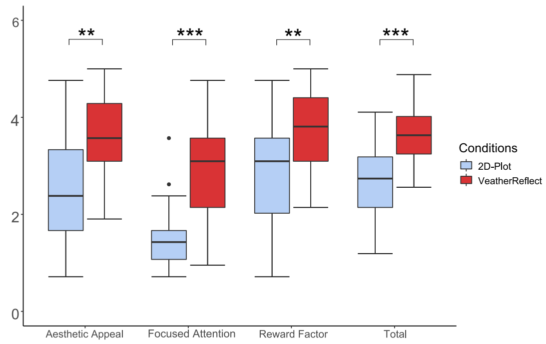


Figure C.5: Significant results of the User Engagement Scale. Condition 2D-Plot is shown in blue, condition VeatherReflect is represented in red. Significance levels are indicated with * for $p \leq .05$, ** for $p \leq .01$ and *** for$p \leq .001$.

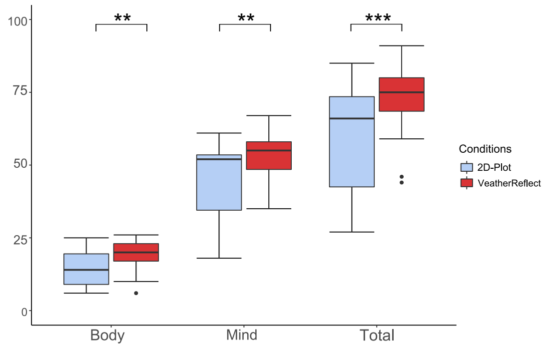


Figure C.6: Significant results for mindfulness as measured by the SMS. Condition 2D-Plot is shown in blue, condition VeatherReflect is represented in red. Significance levels are indicated with * for $p \leq .05$, ** for $p \leq .01$ and *** for$p \leq .001$.

Presence (IPQ)

We used a paired t-test to investigate the effect of VeatherReflect on IPQ and all subscales. In regard to *IPQ-General*, we did not find a significant effect, $t(18) = 1.32$, $p = .78$. Further, we could not find a significant effect in the subscale *IPQ-Inv*, $t(18) = 2.9$, $p = n.s.$ as well as in *IPQ-Spatial*, $t(18) = 2.22$, $p = .14$ and in *IPQ-Real*, $t(18) = 0.31$, $p = .76$. All p-values were corrected using Bonferroni correction.

C.5.2 Qualitative Findings

Based on our qualitative inquiry, we identified four themes: *Interaction and Movement*, *Task-Load and Understanding*, *Recollection and Reflection*, and *Caring and Sharing*. Our findings are described below and illustrated with excerpts from the interviews.

Interaction and Movement

In the condition 2D-Plot, we found that participants would have liked to have more interaction with their data. To illustrate, some participants tried to move items such as single bars to get more information about their data. In contrast, participant enjoyed the interaction possibilities provided in VeatherReflect. They felt empowered to choose if they want to be immersed in a certain weather scenario. Participants reported that having the freedom of choice as well as physically moving towards the weather previews and actively selecting them led to higher engagement, interest and joy when interacting with their data in VeatherReflect, and to increased feelings of immersion. Participants also explained that they felt the urge to move around and stay longer within the weather scenarios to absorb the atmosphere. As an effect, some participants physically reacted to the weather phenomena in that condition. For example, they mentioned shivering and pulling up their shoulders in the snow scenario.

> [VeatherReflect] triggered that I moved around in the environment. The first [condition] didn't do this. And I think that helped me also to get a little bit more invested into the whole experience in the second prototype because I felt a bit more immersed in the environment. (P5)

Task-Load and Sensemaking

Based on our findings, the 2D-Plot offered an objective and detailed visualisation that especially supported getting a quick overview of stress data. Participants appreciated being presented with the maximum value that their stress level could reach. Still, it remained unclear to them how their stress level has to be interpreted, especially in relation to others. For example, participants reported being unsure about what they should aim for: having a stress level similar to the average of 50% or should it be as low as possible. In contrast, participants reported that the aim becomes clear in VeatherReflect, namely being in good weather. Nevertheless, this visualisation approach provides less granular insights, which made it more challenging for some participants to interpret. For example, participants struggled to understand if they were at the lower or upper end within a specific stress level. Along similar lines, they would have appreciated knowing the number of different weather scenarios as a reference point, as they often only experienced two or three weather scenarios altogether. Some participants also questioned why high stress is always mapped to something with negative connotations. As an example, they mentioned that doing sports is a high-stress but positive activity, which would still be represented with a thunderstorm in VeatherReflect. Moreover, VeatherReflect was considered to offer a more subjective visualisation, thus already interpreting the stress scores to some extent. While some enjoyed having a lower task-load through that, others were of the opinion that VeatherReflect was over-interpreting their stress level. Those participants questioned or rejected the visualisation, as the virtual weather was mapped to a more intense stress level than their subjectively perceived stress level. These participants felt that the VR app not only visualised the different levels but also made an assessment of the stress levels in the process:

> [The 2D-Plot] is a more neutral way of visualising data in the sense that the visualisation itself does not attribute the meaning to the stress level. It does not make a judgement on whether it was good or bad stress. It just shows you the level. The second visualisation [VeatherReflect] certainly does make this judgement, because high stress level equals bad [weather]. Thunderstorms, rain. (P19)

Recollection and Reflection

Both visualisations stimulated participants to think about past potentially stressful situations. For instance, they wondered which situation might be depicted by which bar or by which weather. However, some participants mentioned having different and deeper insights about the origin of their stress through VeatherReflect. It helped them understand that external factors such as places or people influenced their experienced stress level. One participant elaborated:

> I was literally in a stressful environment [in VeatherReflect] that triggered stress in me. So, I think that helped me with reflecting: It was not just me who was stressed, but also part of the environment and the whole surrounding was stressful to me. So I think it [VeatherReflect] provided another [conceptual] level of what I could look at and why I experienced stress. (P5)

Furthermore, participants also shared that they spent more time looking at the 2D-Plot in the study than they would normally do due to being in a study. However, they still mentioned spending more time (and wanting to spend more time) in VeatherReflect. It sparked their interest in their personal data, and triggered reflection about behaviour changes regarding dealing with stress. These two quotes highlight these aspects:

> [VeatherReflect] invites you to more exploration. It triggers more curiosity. [...] And it forces you to spend a little bit more time with your data, but in a nice way. (P10)

> I realised [in VeatherReflect] how far I can go. So, now I think about my boundaries outside of this experiment, how much stress is okay, like [how much] rain [is okay], and when to stop. (P15)

Caring and Sharing

Some participants reported that VeatherReflect made them care more about their personal data; it became a personal and emotional experience. While they remained neutral when analysing the 2D-Plot, through VeatherReflect they could recall moments of stress and reflect upon them, which made them relate more to their personal data:

> VeatherReflect makes me more interested in my data. At least in my case, when I am thinking of a stressful situation, I immediately relate it to my feelings. And my feelings for me are not numbers! I feel more connected [using VeatherReflect]. (P17)

Further, VeatherReflect led to emotional experiences. Some participants described that they became more agitated or more relaxed due to the weather they were exposed to. In addition, participants emphasised that the additional sound made the experience more intense than only visually experiencing the weather around them. In general, participants appreciated the experience very much, with some calling VeatherReflect "a poetic and beautiful experience" (P17) that they wished to experience over and over again. Additionally, some participants expressed the desire to invite friends to VeatherReflect, to show and talk to them about their stress levels and discuss how to find long term stress relief:

> Also showing it to others: 'Look, that is how I felt at that moment. So, I think this is easier to communicate and to relive than rather showing 'I had a stress level of 70.' What does this mean anyway? (P8)

On a general note, eleven participants preferred VeatherReflect over the 2D-Plot while six wanted both. Participants emphasised that both complement each other and can be useful in their own right depending on the context and purpose that the user has in mind. One participant suggested:

> You definitely need both, maybe in a sort of layer thing where the weather gives you a nice overview of the whole day so you can see, ah, this were the moments where I might need to dig deeper. And then, when you go inside this particular time frame, then you could add more details there,

> and maybe show different visualisations or map it to the weather with more granularity. (P8)

C.6 Discussion

In this work we endeavoured to understand the effect of presenting stress data with qualitative visualisations such as weather in VR. In this section we first discuss four design recommendations that were derived based on our data. We then reflect on limitations and opportunities for future work.

C.6.1 Design Recommendations

We investigated how a VR application could be designed when using qualitative instead of quantitative representations of complex personal data. On the one hand, the quantitative plot was considered to be more objective, detailed and helpful to get an overview of one's data. Yet, it falls short in creating interest in understanding personal data, which negatively affected engagement and depth of reflection.

On the other hand, VeatherReflect has shown that weather as metaphor for stress data is intuitively understood and can mitigate most of the aforementioned challenges. Although users intuitively understood their data representation, they missed granularity in the presentations. However, higher granularity does not necessarily equal quantitative values and presentations. Instead, this could be realised via levels regarding the intensity of weather or by including a higher number of weather scenarios. Participants also voiced an interest in rankings and a classification system to fully grasp what they experience and to contextualise and compare their data with other people.

Recommendation 1: Qualitative representations of stress data should be accompanied by a reference point that serves as guide to understanding one's data.

Our findings also revealed some insights into specific aspects that created a significantly more engaging experience (UES-Total: $p = .0006$). First of all, participants emphasised the importance of feeling empowered when interacting with the environment. In our case, autonomously being able to decide if, when and how to enter one's data generated engagement. Participants desired even more flexibility, especially in regard of the mapping of weather to their stress levels. Future work could investigate the effects on engagement and reflection when users autonomously select or create the weather themselves. This could mitigate the perception of some participants that the system is over-interpreting their stress levels. Empowering users in that way could reduce dissatisfaction and motivate users long-term, as it addresses one of the universal psychological needs, namely autonomy [483, 608]. Besides significantly better scores as measured with the UES, users also spent more time with condition VeatherReflect (2D-Plot: 2:20min vs VeatherReflect: 5:56min), and explored their data more extensively. This led, in turn, to a perceived increase in depth of reflection, e.g. some participants started considering their environment as one possible stress factor due to VeatherReflect.

Recommendation 2: Qualitative personal data representations in VR should provide interaction possibilities and support autonomy.

Interestingly, our findings showed a significant increase in spatial presence (IPQ SP: $p = .016$) and in mindfulness (SMS-Total: $p = .001$). Based on literature, presence - the sense of being in the VE [536] - can be increased by addressing sensory, vestibular, proprioceptive and interoceptive channels [71, 466], including haptics [348, 607], olfactory elements [341], and thermoception [525]. However, our environment was quite plain, neither providing high realism [255] nor natural settings [130]. Still, the weather scenarios were designed for high realism and included sound. Although participants only stayed a few minutes in each weather scenario, they reported feeling immersed and allowed the weather to affect them, which is also shown in significant increases in presence and mindfulness. Some participants even experienced physical reactions, showcasing an intuitive understanding of weather as a metaphor for stress. While being immersed in weather was the decisive factor, prior literature has also shown that mindfulness and presence can mutually benefit from each other [635], increasing each others effects. Future VR researchers have to master the dichotomy of providing enough feedback to generate presence while designing for simplicity to set a clear focus on key elements.

Recommendation 3: Qualitative representations of data in VR should focus on increasing presence and mindfulness.

Additionally to the aspects discussed above, participants enjoyed the emotional component they experienced in the condition VeatherReflect. They were emotionally involved by the weather scenarios as qualitative representations of their personal data, becoming relaxed or more stressed by being immersed in the weather, and linked these feelings to their personal data. As a result, they increasingly cared about their stress levels, and also reported getting emotionally attached to the application VeatherReflect itself as it provided an engaging experience. This indicates motivation that could be valuable support for long-term usage of our system.

Recommendation 4: To represent personal data in VR, qualitative metaphors that address users on an emotional level could be particularly valuable.

C.6.2 Limitations & Future Work

We acknowledge some limitations regarding our study design. First of all, we decided to reset the smartwatch for every participant, to not have relics that might affect the stress level. However, stress level is partly calculated based on the baseline of resting heart rate, which the smartwatch cannot learn to adequately adjust in such a short time frame. Thus, participants' dissatisfaction with inadequate representation of their stress could be partly due to that aspect. Further, our participant sample is still rather small (N=20) and it included participants with basic and also with very little prior experience of engaging with smartwatch data. Having a homogeneous sample was not a pre-requisite for our study, as we did not strive for interpersonal comparability. Instead our aim was to focus on exploring how new ways of representing data in VR can potentially facilitate reflection and engagement. Here, we focused on the individual framing and understanding of participants. Additionally, the participant sample had varying prior knowledge with VR systems. While all have been familiar with bar charts, this might have led to being more excited by VeatherReflect. To counter this potential novelty effect and to increase comparability of conditions, both conditions were conducted in VR. Yet, we cannot rule out some influence of a novelty effect in the VeatherReflect condition for the more inexperienced users. Furthermore, participants only wore the smartwatch for two to three hours to gather data during their normal day. Some participants reported having sat in front of the laptop while others were physically active during that time. Although we did not strive for interpersonal comparability, some participants received more diverse stress data visualisations than others, which could have led to differences in the amount of insights that were possible. Tracking data for a whole day could have mitigated that problem. Based on our results, we recommend exploring individual stress mappings in future work, i.e. that participants create their own weather representation matching the subjective perception of their stress levels. Additionally, in this study, we explored the potential of weather as a cohesive immersive experience. Thus, the weather scenarios that we explored consisted of different modalities such as soundscapes, lighting, and colour saturation. The decision which weather scenario was accompanied by which soundscape, e.g. that sunny weather was mapped to birds' chirping and the thunderstorm to a loud rolling thunder, was based on realistic scenarios. Future work could investigate the influence that each specific factor presents on the dependent variables, with a specific focus on the role of sound.

Future work, while addressing and validating the design recommendations established in this paper, could further research the following ideas. First, as participants reported becoming emotional during the study, feeling stressed in thunderstorms, one could track and compare their stress levels gathered during the study. Second, to provide more granularity when using qualitative representations one could immerse users in weather as a time lapse, gradually showing each spike. While this would mitigate that problem, it removes autonomy and interaction possibilities from users. Hence we recommend careful consideration, although this research approach appears interesting and valuable to be compared to a more active approach.

C.7 Conclusion

This paper explored how personal complex data (i.e. stress level) could be visualised in a qualitative and engaging way in VR, with the aim to foster reflection. To that end, we presented VeatherReflect – a VR application that visualises tracker stress scores using weather as metaphorical means of representation. Quantitative and qualitative results of N=20 participants showed that VeatherReflect significantly increased engagement with personal stress data and enhanced insights into stress-reducing behaviour. We found that participants felt a significant increase of being aware of one-self, higher interest in engaging with data and more motivation to reflect on their data.

Based on our findings, we derived four design recommendations for VR apps that aim to visualise personal data in a qualitative way: Within a framework, they should provide engaging autonomous interaction that support presence, mindfulness and emotionally engaging experiences. Our work can provide a first step in showing that weather can be a meaningful metaphor to represent tracker stress scores, and that VR can be an effective tool to support engaging with complex personal data. We hope that this paper will inspire further inquiry into qualitative visualisation approaches that effectively support well-being.

C.8 Acknowledgements

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D Mood Worlds: A Virtual Environment for Autonomous Emotional Expression

Abstract: Immersive interactive technologies such as virtual reality (VR) have the potential to foster well-being. While VR applications have been successfully used to evoke positive emotions through the presetting of light, colour and scenery, the experiential potential of allowing users to independently create a virtual environment (VE) has not yet been sufficiently addressed. To that end, we explore how the autonomous design of a VE can affect emotional engagement and well-being. We present Mood Worlds – a VR application allowing users to visualise their emotions by self-creating a VE. In an exploratory evaluation (N=16), we found that Mood Worlds is an effective tool supporting emotional engagement. Additionally, we found that an autonomous creation process in VR increases positive emotions and well-being. Our work shows that VR can be an effective tool to visualise emotions, thereby increasing positive affect. We discuss opportunities and design requirements for VR as positive technology.

Contributions: This paper, exploring the impact of self-creation of the virtual environment to visualise happiness, contributes the following. First, the design and implementation of MoodWorlds – a virtual environment for autonomous emotional expression. Second, an exploratory evaluation of MoodWorlds. Finally, design implications for VR-based SCT that aim to foster autonomy and supper mental well-being.

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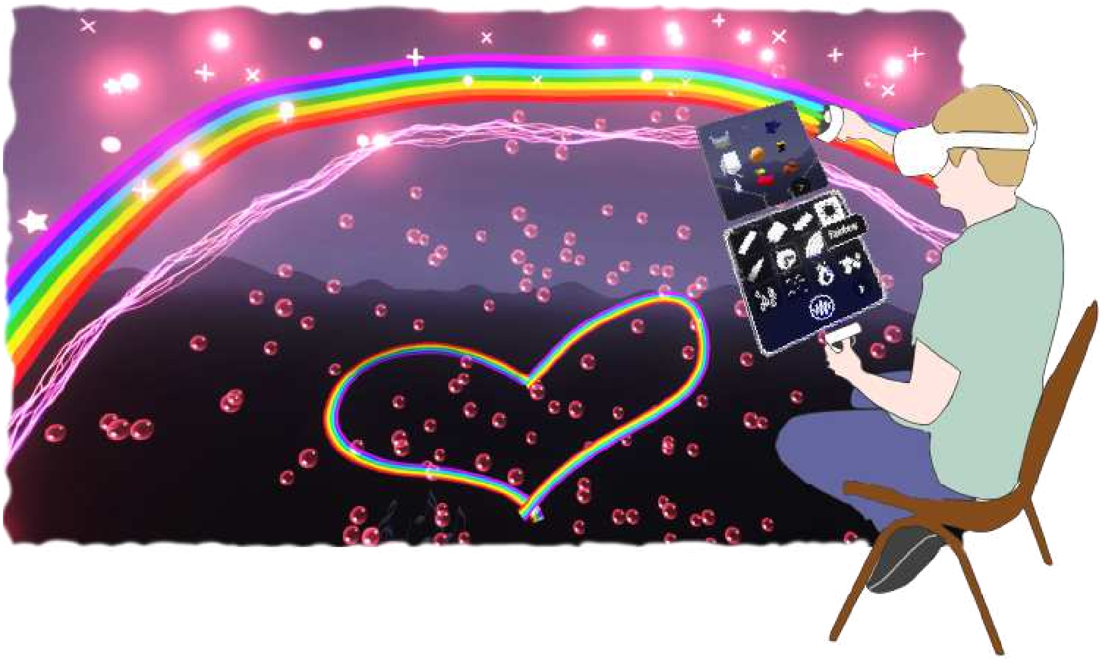

Figure D.1: Mood Worlds - a VR application allowing users to visualise emotions by self-creating a VE. This image is based on the Mood World created by P16.

D.1 Introduction

Well-being and mental health support are commonly addressed design goals in commercial systems and in Human-Computer Interaction (HCI) research (e.g. [66, 491]). Well-being technologies are now commonplace on our wrists (e.g. stress tracker [162]), in our pocket (e.g. digital gratitude diary) or on our computer (e.g. meditation tutorial [333]). In contrast to such interventions, applications (apps) in virtual reality (VR) allow for deep immersion in a virtual environment (VE). VR can reproduce the complexity of real-life situations while variables such as sound, light, movement of objects can be close to completely controlled to provide meaningful interventions [423]. The unique benefits that VR offers for enhancing well-being have been explored in a variety of areas. VR is used, inter alia, for therapeutic interventions (e.g. to treat anxiety [365]), to create a space for artistic expression [90], and in the area of VR gaming and physical activity [505]. Furthermore, previous work in VR explores the potential of VEs in a variety of different areas in the context of well-being such as mindfulness training [387, 333], stress reduction support [582, 636, 546], VR as positive technology [79, 290], role-play and embodiment for positive change [240], VEs for different forms of journaling [33, 170, 574, 583] and emotion regulation interventions [373], among others.

However, most research in the field of well-being and VR focuses on one of the following two aspects: First, many VR apps aim to induce emotions but the participant remains passive. A review by Montana et al. [373] about VR apps for emotion regulation showed that most interventions change the VE *before* the participant enters it. Though differing in experimental manipulation, the procedures resemble one another to a great extent: participants either choose which preset VE they want to experience [50], or they are assigned to a certain condition [331]. Second, other research allows users to personalise a VE, but only to a limited extent. For example, either passively collected physiological data influences the surrounding, e.g. the colour of the VE changes depending on the measured heart rate or brain activity of the participant [331], or the user can more actively influence the virtual surrounding, e.g. by following breathing exercises [440]. This limits the scope for personalisation of VEs as well as the level of self-determination and autonomy it allows for. We define autonomy as being independent and self-governing [326, 547]; as having agency over one's life [527] and, in the context of this study, also over the content and design of a VR app. This lack of providing personalisation and autonomy in VR well-being apps is not only restricted to HCI research but also extends to commercially available VR apps [606]. Therefore, our work focuses on providing a VR experience for personalised, autonomous emotional expression enhancing a user's emotional well-being.

Schek et al. [497] emphasise the need for advanced technologies supporting well-being and promoting health. Furthermore, caring for one's well-being and mental health at home and designing technologies supporting that endeavour has gained in importance [585, 638, 497]. Thus, emotionally stimulating content should be adjusted in real-time if necessary [433]. Recent work suggests that becoming active in designing emotionally stimulating content is in itself therapeutic and can foster happiness [606]. To address these aspects, we developed *Mood Worlds*, a refined and revised version of the VR drawing application Open Brush that allows users to autonomously create a virtual environment with the purpose to express their emotions. A schematic representation is presented in Figure D.1. We conducted a user study (N=16) to inquire how self-creating mood worlds in VR influences the happiness and well-being of participants. We found that autonomously creating a VE to express emotions led to increased happiness and positive affect. We conclude with a set of implications to inform the future design of VR applications for independent self-care and well-being.

This paper contributes the following: (1) the design and implementation of Mood

Worlds–a virtual environment for autonomous emotional expression; (2) an exploratory evaluation of Mood Worlds; and (3) insights for designing future VR applications that foster autonomy and support well-being.

D.2 Related Work

This section introduces the reader to relevant concepts and terms related to emotions and well-being. We then describe how Mood Worlds fits into the space of interactive technologies in general, and VR applications more specifically supporting emotional well-being. We also review examples of how VR is already used to induce emotions.

D.2.1 Emotion, Mood, Feelings and Affect

Positive emotions are one essential aspect of well-being [514]. Well-being, for the scope of our paper best described as a dynamic optimal state of psychosocial functioning [98], is built upon five core pillars that are part of the so called PERMA-theory: positive emotion (happiness, joy, satisfaction, pride, awe), engagement (flow), relationships (work, familial, romantic, platonic), meaning (purpose), and accomplishments (success, mastery). By addressing positive emotions in more detail in this paper, we strive to increase well-being, which in turn affects mental health as an integral part of holistic health and an effective functioning in society [638].

Previous work discusses two different ways to classify emotions: The discrete model according to Ekman [181] defines six basic emotions that are universally identifiable (happiness, sadness, fear, disgust, anger, surprise), while the dimensional approach, i.e. the Circumplex Model of Affect [438], classifies them on two dimensions; valence (negative to positive), and activation or arousal (low to high). More recent research has found that up to 27 emotions can be identified [137]. All of these approaches have in common that emotions are triggered by a specific event or activity [180], are high in intensity, and, as bioregulatory reactions, last for about six seconds [150].

In Psychology, a *mood* is considered to be an *affective or emotional state*. Moods are lower in intensity than emotions, last longer (potentially even weeks or months) [419], and can be influenced by a range of factors, e.g. the weather, relationships, what we have eaten etc. [180]. While emotions and moods are often collectively described as feelings [263], other work [150] defines feelings as a state between emotions and mood. According to the definition by Damasio [150], processing or thinking about emotions, thus cognitively registering them, are called feelings. Consequently, based on Damasio [150], feelings last for longer than emotions and are often caused by a mix of different emotions. For the scope of our paper, we follow the definition of Russel et.al. [438], defining emotions in a fluid way. It is important to note that a specific emotion-triggering event may evoke more than one single emotion [137]. Thus, a state of *happiness* can include other emotions as well, e.g. excitement, satisfaction or awe. Emotions, moods and feelings can be measured with a variety of different methods. The most common are self-reports, such as the Positive and Negative Affect Schedule (PANAS) [619]. Recently, real-time emotion annotation in VR, e.g. by Xue et al. [640], which is based on the Circumplex Model [438], has been added to the list of self-reports. Other ways of measuring the induction of emotions encompass behavioural measures such as body movement, voice pattern, facial expression, or physiological signals, e.g. heart rate, brain activity or electrodermal activity (for an overview, see [433]). Although these measures could provide more objective data than self-reports, most are time-consuming, expensive, and often too complex in their usability for people to use without assistance of experts.

Mood Worlds aims to go beyond past VR systems by offering the first app (to the best of our knowledge) that allows for experiencing positive emotions and feelings by autonomously creating a VE. Furthermore, the creation of a mood world itself takes time. Thus, by allowing the user to immerse themselves into the VE and design it in their own pace, we hope to evoke a positive mood that (ideally) lasts for longer than the actual creation process. This assumption is based on suggestions of related work [467].

D.2.2 Technologies for Well-being

The HCI community and related fields have begun to assign more importance to designing interactions that promote well-being and mental health [427]. This has given rise to new research fields, such as Positive Computing [105], Emotional Design [401] and Positive Technology [79, 204]. Regarding VR as positive technology, research has investigated VR as transformative experience [291, 292], physical activity [505], persuasive technology supporting behavioural change [38], for mindfulness and relaxation [440, 443] as well as emotion regulation [373]. These examples showcase the interest of scholars to explore the design space of (VR) technologies for human flourishing and optimal human functioning, thus supporting the overall psychological well-being [204].

Positive technologies can be classified into two, depending on the definition in three, categories [626, 79]. Hedonic elements induce positive and pleasant emotions [156] while eudaimonic technologies stimulate an engaging and self-actualising experiences, i.e. serious gaming or VR therapy, that support the user in self-growth [156]. Social and interpersonal technologies aim to improve social integration and connectedness [79].

One way of integrating well-being into the design of technology is to address specific determinants or psychological needs such as autonomy, competence, empathy and compassion. [204, 245]. The psychological need most relevant for our study is autonomy. Autonomy can be defined as being independent and self-governing [326, 547]; having agency over one's life [527].

Previous work emphasises the importance of designing for autonomy and emotional expression [106]. The HCI field has contributed a number of systems that considered these aspects in their design (e.g. [114, 285]). However, inquiring how we can support personalised emotional expression in VR has not been addressed yet. Some studies allow participants to choose between a preset of different VEs [50], but most randomly assign participants to a specific condition (e.g. [331, 603]). On a similar note, a recent review of commercial VR well-being apps found that only one app offered the possibility to (partly) autonomously design the environment [606]. Other designers fostered autonomy by actively engaging participants during the design process of a VE, but the design could not be further adjusted after entering the VE [237]. However, research suggests that the process of autonomously designing VEs is therapeutic in itself [606] and that emotional content should be adjusted in real-time [433].

D.2.3 VR as Mood Induction Procedure (MIP)

Emotions, feelings and moods can be actively induced. The so called Mood Induction Procedures (MIPs) are explicitly designed to provoke specific transitory affective states in participants under controlled circumstances [50]. Some MIPs are based on analogue methods such as looking at facial expression [190], interacting with human confederates [303] or doing an Autobiographical Emotional Memory Task (AEMT) [262]. AEMT is a widely used MIP. It is proven to be effective [262], does not require any technology and takes less than 10 minutes [561, 370]. When doing an AEMT, participants write about a specific emotional memory, which can cause them to relive that event. This in turn increases the probability to feel that emotion again [370]. AEMT is a valid MIP, especially for positive mood induction [262]. However, critical studies have found that the intended induced emotion is often accompanied by other incidental emotions that share a common valence [370]. A variety of different MIPs are commonly used in psychotherapy to enhance a mood-congruent recall, which can lead to self-reflection [190]. Reflecting on positive memories can increase positive affect and perceived enjoyment, whereas reflecting on negative memories can promote well-being as well because one can gain emotional distance and achieve cognitive reappraisal of a past situation [299].

More recently, VR has also been used as an MIP [603]. VR can be used to induce fear, which is, for instance, utilised in exposure therapy [365]. However, HCI research has also started to explore VR as a medium for more general well-being support, e.g. its benefits for relaxation [290, 443], and emotion induction [289, 364]. The consensus seems to be that VR is an affective medium whose immersive VEs can evoke emotional states and responses similar to reality [240, 364, 467, 582].

Further research has looked at the impact of specific elements in virtual scenarios [463, 433]. Regarding visual cues, higher saturated and bright colours are more arousing and pleasant [331, 418, 412], fast-moving objects induce a higher arousal [191, 434], and natural settings are perceived as more relaxing [373, 603]. Previous work mainly focused on specific elements of VR. However, in most cases not one specific element but a synergy of colour, sound, lighting, weather, setting, characters, animals and objects induce a certain affective state [190]. Thus, Pinilla et al. [433] have developed broader guidelines for designing visual content of VR applications used to elicit positive change in their users. Moreover, there might be intra- and interpersonal differences of how the same audio-visual stimuli are perceived regarding affective states, also related to personal experiences [433]. As a consequence, visual representations should be personalised as much as possible [433]. Following Pinilla et al.'s call [433], Mood Worlds explores an alternative way to foster well-being and positive emotions. Mood Worlds is designed for autonomous emotional expression in VR, thereby increasing emotional engagement.

D.3 Design & Implementation

Offering autonomy and personalisation in VR in order to allow a visualisation of emotions is a challenging endeavour. As a first step towards defining the design space of such a VR app, we conducted a pre-study in an analogue setting. From those results, we derived design requirements for the Mood Worlds applications. This section will conclude with outlining how we implemented those requirements into Mood Worlds.

D.3.1 Pre-Study: Autonomously Depicting Emotions in Analogue Mood Boards

Most elements that could be used to depict (and to induce) emotions, e.g. colour, weather, animals, environments, among others, have already been well researched individually, primarily in analogue settings (e.g. [412]) and less extensively for VR (e.g. [331]). However, the question remains (1) which elements people will choose if given a choice. Thus, we conducted an exploratory pre-study on expressing emotions in an analogue setting. Results of the pre-study contributed towards the main study by giving a first impression of which elements should be included in the VR setting. Further, we also utilised the pre-study to investigate (2) how the process of autonomous emotion depiction affects the user. What are their thoughts while creating the VE? Which decisions and compromises do they make, and where do they place the most importance?

To that end, we conducted a single factorial between-subject study. The independent variable *visualisation of emotions* was analysed with the three factor levels *anger*, *sadness* and *happiness*. We decided on these three emotions as they are the most induced ones according to related research, as analysed by a review of D'Mello et al. [370]. On the other hand, we strived to include both emotions sharing a common valence (anger-sadness) and emotions from different sides of the valence spectrum (anger/sadness-happiness). This decision is based on the findings that due to a shared activation of affective states, emotions with negative valence might get incidentally induced as well (see sec. D.2.3). Thus, we wanted to see if anger and sadness are clearly distinguishable from each other.

Material

Participants were asked to create so-called *mood boards*; analogue collages depicting a specific emotion in an unrestricted manner. Material to visualise emotions was packed in a box and given to the participants, inspired by the approach by Gaver et al. [208]. Contents of the box included:

- different crayons and felt pens, in pastel shades and bright colours, selected based on colour psychology [412, 418] and to allow free painting from the imagination [493]
- play-dough clay, based on research about haptics and using sandboxes to express oneself [493]
- a set of 30 postcards/photos (10 per emotion), based on the notion that the process of selecting images is likely to be an expression of self-expression, facilitates spontaneity and represents self-opening [277] and that the so called magazine picture collage technique is beneficial for people without artistic talent [132]. Those images can depict any context, e.g. activities, everyday objects, nature, or caregivers such as families [277]. Having the VR study in mind, we decided against adding pictures depicting humans for several reasons: therapists expressed concerns about feeling watched when avatars share a mood world [606], and research suggests that humanoid avatars could lead to several negative implications for

HCI due to the uncanny valley effect such as distraction and distress [509]. Photo content was, thus, selected based on valence and arousal scores of the OASIS data base [302], depicting animals, objects and scenery. For the emotions of anger and happiness, ten photos were selected accordingly. However, the identified sadness pictures did not depict sadness, but rather disgust in the view of the authors. Hence, photos were derived from mood boards available on the Internet. From a pre-selection of 15 pictures chosen by the authors, ten were finally selected based on the assessment of five people not related to the study. Other items available to the participants for their constructions included:

- items we provided, e.g. scissors, glue, rubber, pen, cardboard as mood board, several pieces of paper, and sweets as a treat.
- personal items. Although not included in the box, participants were informed they could use any personal item (photos, 3D-objects, etc) that they wanted.

Participants

We conducted interviews with $N = 12$ (6 female, 5 male, 1 nonbinary) participants ($M = 30.8$ years, $min : 24$, $max : 57$) with differing nationalities (eight German, three Austrian and one Russian). Four were PhD-students, two were teachers, one was a student, one a secretary, one an IT worker, one a software consultant, one a mechanical engineer, and one a lawyer. While selecting the participants we ensured that they were not subject to any psychological illness such as depression and were in general in a good state of mind, to minimise the risk of having lasting effects of negative emotions.

Procedure

Due to the importance of autonomy in our research (see sec. D.2.2), we emphasised towards the participants that they should be by themselves in the comfortable setting of their home for the duration of the study. Participants received the box containing the study material and an instruction sheet, which was fully disinfected due to the current COVID-19 pandemic, at their homes. When they were on their own, they had time to inspect the contents of the box, then emotions were induced using an AEMT as MIP (see sec. D.2.3). Participants were asked to write about a recent experience that made them, depending on the randomised condition, angry, sad or happy so that others might feel the same by reading their text. Directly after, they designed their analogue mood board. In the end, a semi-structured interview was conducted via Zoom and the box with the material and the mood board was picked up again.

Happiness	Anger	Sadness
Colours: Red, Pink, Orange, Blue, Violett, …	Colours: Red, Black, Yellow, Orange, Blue	Colours: Black, Grey, Brown
Words (20): Family, Protection, Support, Wild, Huge, Hope, Love, Unstoppable, …	Words (6): Pow, Desire, Go F*** Yourself, DoucheKingdom	Words (15): RIP, Emptiness, Helplessness, Disappointment, Powerlessness, …
Elements: (happiness) elephants, fireworks, heart, oranges, dog, rainbow, flowers, present (sadness) desert (unallocated) snow, bubbles, thumbs-up, stars, clouds	Elements: (anger) explosion, wolf, captured dog, knife, strangling snake, tornado (sadness) tear, broken glass, desert, crashed plane, flower on concrete (unallocated) boxing gloves, sword, prison, low battery, cannon	Elements: (sadness) clouds, broken glass, tear, crashed plane, flower on concrete, candle, raven, rain (anger) strangling snake, gun, captured dog (unallocated) forest

Figure D.2: Mood boards created by the participants. To get insights and ideas of what would be needed for transferring mood boards to VR, we analysed the number and variety of colours, words and elements. Implemented photos by participants that were previously allocated to a specific emotion are listed accordingly. Newly emerging elements are called "unallocated".

Data Analysis

As we did not impose any time constraints, users took on average $M = 21$ min to complete the AEMT (min : 10 min, max : 34 min). The content of the AEMT was not analysed further, as the focus of the pre-study was the content of the mood boards. The creation of the analogue mood boards took the participants on average $M = 28$ min (min : 20 min, max : 49 min). Based on the method of exploratory principal component factor analysis by Gutbezahl [235], we analysed the objective number of colours and written words used in the mood boards. Further, we investigated if elements reoccurred in the mood boards. The semi-structured interviews lasted on average 18 min. Interviews were transcribed verbatim and analysed by two authors using a thematic analysis approach [83].

D.3.2 Design Requirements

Based on the analyses of the mood boards (see Figure D.2) and interviews, we derived the themes *Flexibility of Input Methods*, *Single- and Multi-colour* and *Induced Mood States*. Each theme and its implications for the main study will be presented in the following.

Flexibility of Input Method

One theme was the flexibility of creation methods. Participants enjoyed the autonomy during the creation process:

> It was also a bit of fun to think about how I could present this and then simply enjoy this freedom, to simply be allowed to do it. (P1)

Nine participants used photos. They claimed that implementing photos either supported their creativity or were used to tell a story. Participants often used pictures that were originally attributed to represent another emotion as the one they depicted (see Figure D.2). This was especially true for elements allocated to anger and sadness. In line with related work, this could indicate that the AEMT induced incidental affects with shared valence [370]. However, three participants exclusively wanted to use individual drawings and three participants additionally used clay or personal elements to express their mood. As a reason, they stated that by drawing or using personal items they could better express their individual experience. For example, participant 5 elaborated:

> I actually looked through the photos first and pulled out a few photos that I associate with anger. But then for my board it was important to me to really visualise specifically what my situation was like. And then the photos didn't fit so well for me personally and I thought it was better if I just drew it. (P5 - anger)

As a result, Mood Worlds offers both drawing possibilities and pre-defined 3D objects to appeal to all participants and to guarantee a maximum of flexibility. Further, some elements will be animated, such as fireworks, to better show what P12 describes with the words "unstoppable, wild, outburst" on their mood board (see Figure D.2).

Single- and Multicolour

In line with previous work, colour was a key aspect of mood boards [412, 418]. Sadness was depicted either in few, subdued shades or completely colourless. For this emotion, uniformity was a recurring theme, where participants wanted to have one predominant colour for the whole mood board. In contrast, the amount of colours as well as the saturation increased significantly for anger and happiness mood boards. In fact, the happier, the more colours were used (see Figure D.2). The following quotes illustrate:

> I wanted to convey the vibrancy of feelings, of emotions, and hence the vibrancy of colours. (P4 - happiness)

> I have tried to accommodate ALL colours. (P6 - happiness)

Although these findings were anticipated due to similar findings in colour psychology [412, 418], we now know to place special importance on offering all shades of colours with differing saturation. Further, Mood Worlds will offer the possibility to completely adjust the surrounding light as well. Thus, we implement two panels, one for adjusting the colour of brushes and another for the lighting setting of the surrounding environment.

Induced Mood States

Participants had the task to visualise one emotion, happiness, anger or sadness. However, similar to findings of previous literature (see sec. D.2.3), participants reported the elicitation of several other incidental emotions of the same valence:

> There are so many ways to be happy, you can be calm-happy, you can be satisfied-happy, you can be excited-happy, lovingly-happy. There's just so many dimensions to that. (P4 - happiness)

Participants were immersed in their respective emotions for nearly 30 minutes. This process was perceived as fun and therapeutic. Additionally, this long-lasting visualisation process resulted in stronger emotions for some participants. In summary, we found that the AEMT was successful as MIP, and that the visualisation process upheld and prolonged feelings. However, results were unclear on one point: some participants reported that the process of visualising emotions itself was so fun that it increased the mood, while others expressed concerns about being too involved with negative emotions. This dichotomy is best illustrated by these quotes:

> It actually gave me a kind of satisfaction in the end. The more I painted, the happier I was actually because I had manifested my thoughts in this way. (P1 - sadness)

> I hope the other people who got anger and sadness don't get so carried away as I did. (...) I would probably have gotten involved in exactly the same way and then I don't think that I would have felt as good. (P6 - happiness)

Figure D.3: Customised panels attached to the left controller in Mood Worlds. They are placed in an angle of 45° and can be navigated by using the joystick.

These findings have two implications for Mood Worlds: First, as AEMT was successful in our specific setting, we will also apply this MIP in the main study. Second, the inconclusiveness of participants regarding induced mood states makes us hesitant to use Mood Worlds to visualise negative emotions. Negative affective states might be mitigated, which would imply that VR is an effective positive technology. However, literature also suggests that VR can elicit similar, if not even higher valence and arousal than reality, both for positive [467] and negative emotions such as utilised in exposure therapy [364]. As participants' opinion differed strongly on this matter, we cannot foresee the specific effect VR might have on the intensity of emotions. Effectively, we will solely focus on eliciting and visualising positive affective states in this study.

D.3.3 Final Prototype

Based on the design considerations derived from the pre-study, we modified the VR painting app Open Brush, a fork of Tilt Brush by Google, which was made open source in late January 2021 [6]. We extended and customised its basic functionality which resulted in our self-care VR app called Mood Worlds. Our final prototype is described in the following and is shown in Figure D.3.

- *Environments*. We utilised three of the original pre-defined Open Brush environments and added three others: *island* shows a small sandy island with palm trees, *meadow* is a grassy slightly hilly landscape, and *mountains* shows mountains and small trees from afar. Level of realism (*island* = high, *meadow* = middle, *mountains* = low) differed, as did the impact lighting and colour had on the surroundings (*mountain* = high lighting impact, *meadow* = middle lighting impact, *island* = low lighting impact).

- *Add Ons.* This self-designed panel allows users to (de-)activate three animated additional elements. Based on prior findings, environments could be thus enhanced by butterflies, fireworks and flowers.

- *Brushes.* We reduced the amount of original brushes (50+), of which some are animated and have sound effects, because we do not want participants to feel overwhelmed and dissuaded from the task of expressing their own emotions. Additionally, we added a self-created rainbow-coloured brush. We want to highlight that choices for omitting and adding brushes were based on the high frequency of comparable one's in the pre-study's mood boards, such as rainbows, bubbles and stars. In total, we included 14 variations of brushes.

- *Objects.* Inspired by Open Brush's Media Library panel, FBX-models of 3D-objects, that are stored locally on the participants' computers, can be added to the scene via this panel. These pre-defined objects can be manipulated in size, moved around, and deleted by throwing them away into space. To receive more input about which objects to offer, we asked 18 (10 female, 8 male) people unrelated to the studies what they associate with happiness. Their replies, e.g. cars, butterflies or barbecue smell, were then implemented or substituted with close equivalents.

- *Colour & Lighting.* The colour panel and the lighting panel were not changed from their original counterparts. They allowed adjustments to the brush-colours and the colour, intensity and saturation of the light in the scene.

- *Tools.* We reduced the amount of tools available, to not overwhelm users. Mood Worlds only offers the erase, repaint, teleport and the undo/redo tools. Further, participants could resize themselves to get another perspective on the scene. The basic functionality to save sketches remained untouched.

With all these functionalities, Mood Worlds meets the specific design consideration of XR experiences for eliciting positive affective states and supporting a positive change in users, as established by Kitson et al. [290]. Our design is also inspired the PERMA model of well-being by Seligman [514], which employs play and positive psychology. As input modality, we use VR controllers. Interaction strategies that Mood Worlds addresses encompass nature, play and mood induction. Output modalities encompass object appearance as well as light and colour of VEs [290].

Our application especially targets autonomy as determinant of positive technologies. It comprises both hedonic and eudaimonic elements of positive technologies. Mood Worlds is intended to induce pleasant emotions in users by self-designing the VE while being in a positive affective state, and it offers an engaging and self-actualising experience that could foster self-reflection and well-being.

D.4 Evaluation

We called our application "Mood Worlds", which would technically mean that we only identify and change longer lasting moods. However, we do include and measure high-intense short emotions (that may be evoked by specific objects and events in VR), as well as feelings (as participants will be asked to reflect upon their emotions), and moods, as the creation of a mood world itself takes time, and on top of that might evoke a positive mood that (hopefully) lasts for even longer than the creation process. Mood Worlds is evaluated via an exploratory remote VR study, following considerations by Ratcliffe et al. [448] that VR is a suitable medium to collect data remotely. Further, Mood Worlds targets VR users who want to engage with their emotional well-being and mental health at home. Thus, it seems logical to do a remote study in the same setting as it is intended for, namely while comfortably alone with one's feelings at home. As an additional benefit, specific COVID-19 related hygiene considerations do not have to be taken into account. This section first presents how we collected the data, introduces our participant sample and procedure. Then, we present our quantitative and qualitative results, focusing on the themes of *Empowerment*, *Energetic Representations*, *Emotional Experience* and *Use Cases*.

D.4.1 Participants

We used our extended social network and snowball sampling to recruit participants. In total, $N = 16$ (6 females, 10 males) participants took part in the Mood Worlds study ($M = 27$ years, $min : 18$, $max : 33$) without receiving remuneration. Two were Greek, the rest of German nationality. Our sample consisted of eight PhD students, seven other students and one project manager. People interested in participating but who did not own a VR system at home were able to borrow an Oculus Quest 2 for the duration of the experiment. Ten participants had tried out VR less than ten times in their lives, two use it about five times a year, one once a month and three several times a week. For an overview see Table D.1.

Table D.1: Overview of our participants. Participants that also have been taking part in the pre-study are marked with asterisks (*).

	Age	Gender	Nationality	Occupation	VR System	VR Usage
P1	29	male	German	Project Manager	Oculus Quest 2	< 10
P2	28	male	German	Student	Oculus Quest 1	weekly
P3	18	male	German	Student	Oculus Quest 2	< 10
P4*	28	male	German	PhD	Oculus Quest 2	5x per year
P5*	28	male	German	PhD	Oculus Quest 2	5x per year
P6	29	male	German	PhD	Oculus Quest 2	< 10
P7	26	female	Greek	PhD	Oculus Quest 2	< 10
P8	26	female	German	PhD	Oculus Quest 2	< 10
P9	25	male	German	Student	Oculus Quest 2	< 10
P10	28	female	German	PhD	Oculus Quest 2	< 10
P11*	29	female	German	PhD	Oculus Quest 2	weekly
P12	33	female	German	Student	Oculus Quest 2	< 10
P13	24	male	German	Student	Oculus Quest 2	< 10
P14	25	male	German	PhD	Oculus Quest 2	once a month
P15	26	male	German	Student	Valve Index	weekly
P16	23	female	Greek	Student	Oculus Quest 1	< 10

D.4.2 Data Collection

Quantitative data was collected from two questionnaires (Panas and Oxford Happiness Questionnaire). Further, we gained qualitative insights through interviews.

Measures

We used the PANAS questionnaire [619] to measure affective states of users before and after experiencing Mood Worlds. PANAS consists of a list of 20 adjectives used to describe 10 positive emotions and 10 negative emotions. Participants indicated on a 5-point-Likert scale if they feel these emotions in that specific, short-lived moment. Further, the Oxford Happiness Questionnaire [248] was used in the same manner to indicate changes in happiness and well-being. Contrary to the PANAS, it rather indicates eudaimonic elements by measuring a lasting impact on happiness and well-being. Results from the pre-study suggested that some participants felt uneasy by having to record the time spent with creating the Mood Boards. Thus, we decided against measuring the time needed per sketch in the main study.

Interview Protocol

We conducted semi-structured interviews that lasted on average 16 min. All audio recordings were transcribed verbatim and imported into MAXQDA software. Two authors both coded two interviews using open coding. Next, a coding tree was established through iterative discussion. The remaining transcripts were coded individually by one author using the coding tree. A final discussion session between two authors was conducted to identify emerging themes using thematic analysis [83]. The Mood Worlds have all been re-experienced in VR by one author to further understand the meaning of the interviews and to help with identifying themes.

D.4.3 Procedure

A link providing remote access to the Mood Worlds study was distributed via various platforms such as Discord groups and university mailing lists. By clicking on the link, participants were forwarded to a Google form, which guided them through the whole study. It included detailed information about the study, contact information of the first author, a consent form, questionnaires, instructions for technical set-up, a short tutorial video (see supplementary material), and contact details to reach out to the experimenters who then set up date and time of the post-test interview with each participant individually.

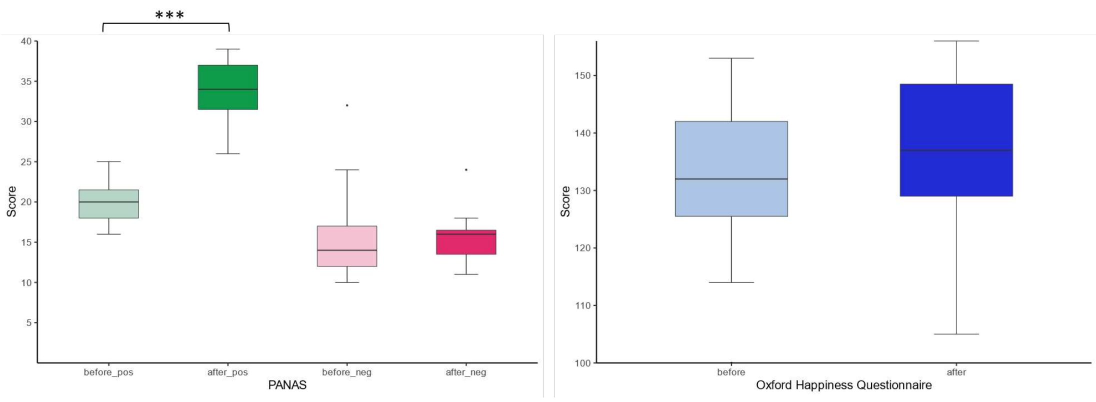

Figure D.4: Results of the PANAS questionnaire, categorised in positive and negative items before and after experiencing Mood Worlds (left). Results of the Oxford Happiness Questionnaire, divided into scores before and after Mood Worlds (right). Statistically significant results are marked with asterisks (*).

Similar to Prpa et al. [440], for example, we chose an exploratory study design. First, after giving consent, participants filled out the PANAS questionnaire [619] and the Oxford Happiness Questionnaire [248] to establish a base line of emotions felt at that moment. Then, participants set up VR, watched a tutorial, and tried out Mood Worlds without any task given to get familiar with the functionality. Afterwards, a positive affective state was induced using an AEMT as MIP. To make it more approachable for participants, they were asked to recall a happy memory from their recent past, but we also welcomed incidental emotions sharing the same valence, such as excitement, satisfaction or awe [137] as we were striving to create general mood states instead of specific emotions, as recommended by D'Mello et al. [370]. To make use of the emotions as best as possible, and because the pre-study had shown that the AEMT successfully induced emotions for our setting, we did not measure induced emotions via questionnaires again at this point in time. Instead, participants directly started with creating the Mood Worlds. Afterwards, participants answered the PANAS and Oxford Happiness Questionnaire a second time, then contacted the experimenters who conducted a post-test interview as soon after the study as possible.

D.5 Results

Based on the evaluation, we gathered quantitative results from the questionnaires as well as qualitative insights from the interviews. Our findings will be presented in this section.

D.5.1 Quantitative Results

Participants reported spending approximately between 5 and 30 minutes to construct their Mood World. Each participant created a single Mood World, resulting in 16 sketches to analyse. Six participants used the island environment, three night sky and meadow each, and two the mountain and the standard environment. Four participants used add-ons (all of them), and four adjusted the colours and lights of the VE. Eleven participants utilised pre-defined objects to enrich their Mood World (min = 0, max = 10 kinds of objects). In line with the pre-study, Mood Worlds were overall bright with a lot of colours. Though hard to count due to various shades used, Mood Worlds were made up by 3.44 (min = 1, max = 6) distinct colours on average, mostly yellow (used in nine Mood Worlds), pink/magenta, red, orange and white (six each), followed by blue and green (five each). This does not include various shades of one colour (e.g. light blue and dark blue would be counted as one colour), the seven colours of the rainbow brush, and colours of pre-defined objects. Thirteen participants used animated brushes. The list is led by blinking stars (eight), plasma (six), smoke (four) and bubbles (three). Seven types of non-animated brushes were used. Nine participants used both animated and non-animated brushes. The specifics can be found in the supplementary material.

The data of the PANAS and Oxford Happiness Questionnaires were analysed using the Wilcoxon signed-rank test for paired samples with Bonferonni correction as post-hoc test. It was measured on a .05 confidence level. The results are shown in Figure D.4. One data set had to be removed due to incomplete data. Results of the PANAS questionnaire are presented in Figure D.4. We found a statistical significant difference between positive emotions when measured before and after experiencing Mood Worlds, $p = .00$ (before: $M = 20.2$, $SD = 2.7$; after: $M = 33.7$, $SD = 3.9$). Participants felt significantly better after Mood Worlds. Felt negative emotions differed insignificantly between the time of measurements, $p = .42$ (before: $M = 15.6$, $SD = 5.8$; after: $M = 15.6$, $SD = 3.1$).

We further measured happiness with the Oxford Happiness Questionnaire, again before and after completing Mood Worlds (see Figure D.4). There were no significant differences, $p = .31$ (before: $M = 131.8$, $SD = 14.3$; after: $M = 137.6$, $SD = 14$).

D.5.2 Qualitative Results

Based on our qualitative inquiry, four themes were derived from the data: *Empowerment*, *Energetic Representations*, *Emotional Experience* and *Use Cases*. Our findings are described below and illustrated with excerpts from the interviews.

On a general note, some experienced technical issues, especially due to movement restrictions due to the cable being attached to the PC. Some also mentioned needing time to get adjusted to the complex functionality. They did not mention any other cognitive burden. However, all participants found the system still intuitive to use after the trial phase, and stated that with a more frequent usage they would feel even more confident. More importantly, all the participants enjoyed using the application, and stated that it was worth their time.

> It's an easy tool to use, I think. And it brings you happy feelings. (P16)

> It was very positive, both for my well-being and my creative possibilities. It was a positive experience. (P6)

Empowerment

The first theme derived from our data focused on what participants feel empowered to do in the Mood Worlds application. The theme consists of three codes: *Autonomy*, *Self-Confidence* and *Creativity Through Constraint*.

Participants especially enjoyed the flexibility and free choice that Mood Worlds offers. They liked that they had the *autonomy* to design the environment how they liked it, and found joy in trying things out quite freely. They further emphasised the benefits of being allowed an own choice, as participant 11, for example, emphasised:

> You were just so free, like with the example of the people and the armchairs. I could have drawn stick figures, but you could also choose armchairs or something else [to represent people]. Just to have the possibility to decide, that was great. (P11)

The range of choices how emotions can get visualised can be seen in some example sketches in Figure D.5.

As a second code, we found that Mood Worlds enhances *creativity through constraint*. As an explanation, the feature of adding pre-defined environments and objects to the scene provided a framework. One participant elaborated:

> Somehow you had a certain framework within which you moved, it wasn't completely free, so that I could design everything myself, I had certain guidelines. (...) But I somehow had the feeling that by trying out and experimenting with the possibilities I had, I realised relatively quickly: This somehow fits my feeling. So, for example, fireworks, that's what I associated with it without knowing before. (P12)

A. Gaming Evening with Friends (P2) B. Sunset Beach Scene (P4) C. Swirls, Colour, Smell and Taste (P12)

Figure D.5: Sample sketches from participants.

Effectively, the restraints through pre-defined settings actually supported the creativity process of some. Participant 1 and 2 elaborated:

> At first I didn't know what I should draw at all, because conveying emotions in a drawing is in itself hard, I think. Since I can't draw anyway, it wasn't that easy at first. And then it was made easier by the fact that you could bring these pre-fabricated objects into it. (P1)

> There were a lot of objects that also fit to a variety of different scenarios. And that also stimulated the creativity to see: Which could fit in my case? What could I put in there that could reflect my scene? (P2)

Nevertheless, some participants reported being concerned, at first, about the aesthetics of their scene. Many mentioned not being an artist and not being able to draw well. Thus, they were worried, as the following quote shows:

> I was also a little worried at the beginning whether it would be aesthetically pleasing afterwards. (P7)

However, participants gained *self-confidence* in their creative skills with the help of Mood Worlds. All participants were satisfied with their results in the end. Participant 10 reflected:

> Actually, I think it [Mood Worlds] is a very good tool, because I thought, actually it makes everything look just nice. (P10)

Energetic Representations

The second theme describes what participants can design and how this affected them. The theme encompasses three codes, *Corporeal Emotions*, *Reminiscence of People* and *Energy & Motion*.

Some participants chose to recreate the situation of the AEMT quite graphically, either by reconstructing a scene (e.g. Figure D.5A) or by extending pre-defined environments through objects, drawings and by adjusting the lighting (e.g. Figure D.5B). These participants wanted to immerse themselves again in the past experience. As an example, participant 4 stated:

> I tried to recreate as closely as possible with the possibilities I had there (...) that you can continue [in thoughts] where you left off. (P4)

Other participants consciously chose a more abstract design method (e.g. Figure D.5C). Some emphasised the importance of colours and others the desire to express what was in their head, as exemplified in the following quotes:

> You can't actually see feelings, but nevertheless I associate certain feelings with certain colours in my mind's eye. (P10)

> I didn't have the ambition to make it completely real, because it was already clear to me that showing emotions doesn't necessarily mean that I'm making something photo-realistic, but that it's more like I had it in my head. (P6)

Thus, Mood Worlds helped to give emotions a visible, nearly physical form, to design *corporeal emotions*. Some even expressed the desire to physically touch the emotions. These aspects were described as follows:

> I actually had no idea at first what the feeling looked like. Because you don't see a feeling, you feel it. And because I then had these different possibilities [in Mood Worlds], I was able to try things out a bit. (P12)

> I thought to myself, you could really stand in my work of art, in the middle of it, and feel it [participant does meandering movement] everywhere. (P10)

Besides the relation between emotions and haptics, participants also included other senses in their mood worlds. Some added objects they associated with something they enjoy or made them feel relaxed, reminding them of a special taste (e.g. blueberries) and smell (e.g. coffee beans, e.g. see Figure D.5C):

> I chose [the blueberries] because I like eating blueberries. I put the coffee beans there because I like drinking coffee and I think that's such a positive pleasure, also the way it smells.

Besides giving emotions a physical form, happiness was also often associated with people and the resulting feeling of togetherness. Beloved ones were often at the forefront of thoughts when creating Mood Worlds. We call this code *Reminiscence of People*. For example, participant 10 wanted to remember a friendship and created a VE which would suit both of them. Participant 4 gave homage to a romantic relationship by having the partner in mind while creating a rosy and romantic environment, and participant 11 was inspired by the memory of a recent family visit and created the Mood World to regain the feeling of togetherness.

> I wanted to remember our friendship, so to speak, and take that with me. (P10)

> I remembered my partner (...), this being in love and this rosy and romantic and also very happy feeling. (P4)

> It felt like home that way. (P11)

Users reported that they either represented humanoid avatars via objects (e.g. see Figure D.5A) or that they used objects as placeholders to support a *reminiscence of people*:

> An avatar would never look exactly like that person. And then, I think, I would perceive that as a foreign person. (P11)

> You don't need avatars. I mean, you can do like metaphors. (...) So with the teddy bear, it represented my younger cousin. (P16)

> In my memory I can fill in this armchair (...) and in my imagination I sort of complete it. (P11)

Apart from realistic and abstract depiction of emotions as well as using objects to represent and remember people, happiness and movement were also often described as positive *energy and motion*. Ways of such energetic representation varied. For example, participant 6 had a volleyball game in mind and drew the positive energy that he felt in this situation:

> So I didn't draw the players but only the energy that goes back and forth over the net, you could also see it as a ball exchange, the positive energy that goes back and forth and there is an exchange between the two sides (...). With the plasma tool I immediately had the feeling, oh yes, that is the positive energy.

Some participants used round (animated) shapes to represent the energy they felt during a real-life situation (e.g. see Figure D.5C). One participant reflected on using animated winding lines drawn in their Mood World.

> Happiness for me is not an angular shape, but rather a round, soft shape. And that's why my painting has no corners. And snake movements have something calming for me, something positive, and I tend to associate it with happiness. (P10)

Others commented on the importance of including movement in the scene itself. It represented activity and life. Movement was represented via animated brushes, such as in the plasma brush or blinking stars, and could be found in animated objects, such as butterflies or fireworks.

> [Movement represents] more life in the scene and that's why I thought it was great that something [butterflies] was buzzing around and moving. (P6)

> The feeling of joy, of being active, was reflected through the movement (...) it also moves a little bit after you have drawn it, it is also a little bit pulsating and somehow also shows activity. (P12)

Some participants also touched upon the unique way of VR to immerse them in a 360° digital world and which allowed them the opportunity to physically move through one's emotions. These quotes illustrate this aspect:

> My feeling is somehow with me and then everything is all around my body and then I have also designed around my body. (...) An emotion circle (...), because I realised: 'Oh, you can design around yourself easily.' That freed me. (P12)

> You are not much in 3D, in VR, and it's kind of cool as soon as you realise that you can do something in three dimensions. (...) I want to do things where I can run through like this. So I can kind of stick my head into a swirl or something [participant looks around themselves in all directions]. (P5)

Emotional Experience

Participants experienced a variety of emotional sensations in Mood Worlds. This theme is divided into four codes, *Childlike Excitement*, *Happy and Safe Place*, *Inspiration* and *Reflection*.

Users of Mood Worlds felt *childlike excitement*, wonder and awe. For instance, one participant compared it to a precious childhood memory:

> It's that feeling, the childlike feeling, that's something new and I felt a bit like I did when I first got my Nintendo, I also had that feeling: Oh yes, great, this is mine now, what can I do with it now? It's going to be fun. And that's exactly how I felt here at the beginning. So full of anticipation. (P3)

Childlike excitement further showed itself in impulsive behaviour and spontaneous drawings. The following quotes highlight these aspects:

> (...) somehow having an environment where I say: oh yes, this is a happy environment and then I didn't think so much about the actual situation. (P14)

> There was a bit of childlike joy for experimentation, where I just tried things out and there was no right or wrong. (...) As an adult, you are often very focused on the cognitive and perhaps go into something with a plan. And I didn't have that now because it was supposed to represent a feeling, where I didn't have any direct visual planning beforehand. (12)

On the other hand, some Mood Worlds showed a more calm-happy and mature setting, which focused on creating a *happy and safe space*. Participants expressed a desire to create a protecting, carefree and relaxing atmosphere. They imagined being there for being mindful of oneself or meditating. In such happy places, participants felt relaxed, had no negative thoughts.

> [I created this] protecting, relaxed, carefree atmosphere. (P11)

> [I felt] a kind of inner peace. (P2)

A key reason why Mood Worlds was perceived to have calming effects was due to facilitating immersion. Presence made it possible to take a break from reality and dive into another virtual world. Participant 12 reflected:

> You were really in there in this world. And, yes, I had the feeling that I had actually forgotten the outside while I was in there (...). I forgot all the stress that was actually today. (P12)

Besides feeling excitement and awe, as well as to just exist in a relaxing and happy place, participants also felt actively involved. Mood Worlds supported them in their *reflection* about their own feelings. One participant referred to the experience as being meditative and at the same time reflective. In particular, the duration of Mood Worlds was perceived as beneficial in this regard. For one reason, participants stated that by spending time visualising emotions, they experienced more head space for deep reflection about their emotional affect. Nevertheless, as no time limit was given, Mood Worlds felt like a short-lived experience. These aspects are well expressed by these quotes:

> I also think it's kind of nice when you recall such a happy experience and reflect on it and then meditate on it for half an hour and visualise it a bit. That is a beautiful exercise. It was fun. But at the same time it was also short-lived. (P10)

> It [Mood Worlds] hasn't strengthened the feeling, but perhaps it has somehow internalised it a little more, because I spent a certain amount of time with it. Normally I remember the moment briefly and ah yes, nice, and then, a few seconds later, I'm back to everyday life. (P11)

While reflection is directed back to what was in the past, Mood Worlds also evoked *inspiration*, which points towards the (near) future. Besides feeling inspired, it also gave the participants strength for the near future. Further, it was mentioned that one can regain perspective by receiving a positive reality check.

> I have found this very inspiring, like creating my own world this way. (P12)

> It also brings back a bit of perspective or that levels you a bit. (...) This gave me a bit of a reality check again. (P11)

Thus, emotional experiences were induced and lived by all our participants for the duration of Mood Worlds. However, some also reported a lasting effect of the induced happiness, as participant 8, for example, reflected :

> So I actually thought about whether that [Mood Worlds] somehow made me happier and I had the feeling that I sat there afterwards, grinning happily, and thought: Okay, yes, it seems to be like that. (P8)

Use Cases

In the last theme, *Use Cases*, participants imagined how they could use Mood Worlds in the future. Use cases encompass *Intrapersonal Experiences*, *Interpersonal Experiences* and *Negative Emotion Worlds*.

A big focus of many participants was to have an *intrapersonal experience* in which they designed just by and for themselves. Participant 11, for example, stressed:

> That's for me now, I paint it the way I think it and the way I can. And that's how it is. And it doesn't really have to be pretty or appealing. And that's enough for me, as long as I know what means what and so on. And then that is completely sufficient. (P11)

Some further imagined repeatedly using Mood Worlds. One could even say that they wanted to share their own feelings presented in a former Moody World again with themselves. By using Mood Worlds more often, participants imagined gathering a catalogue of different self-designed places which they could re-experience and repeatedly re-design if they wished. For instance, participant 8 and participant 12 elaborated:

> I think I would like to do that more often, go back I mean. (P8)

> It would also be exciting to have different places where you could travel to and where you could create again. (P12)

Apart from placing the importance on the self, there were also others who could fathom having *interpersonal experiences* by sharing the experience with others. By interacting with others, they imagined strengthening the relationship with friends, which further supports creativity through this multi-personal design process.

> (...) to have another one with you and you both draw together. (P7)

> I could also imagine that it would be really interesting to experience this creative process together with other people because it's just fun to be able to see each other a little bit and just interact, so to speak. (P5)

As a last use case, some participants envisioned that Mood Worlds could also help them when feeling down. As already elaborated on above, relaxing emotional states occurred frequently with the Mood World's application when a positive mood state is induced. Moreover, some participants mentioned that *negative mood worlds* could be also beneficial when in a negative affective state. Participant 10 clarified:

> If you had a really shitty day, then that [Mood Worlds] could help. (...) You feel emotions and let go of them and then you feel better. And in VR with such an anger painting, it also ends when you take off the VR-glasses, and I could imagine that being helpful. (P10)

D.6 Discussion

In this work we endeavoured to understand how self-designing a VE affected emotional engagement and well-being. The quantitative results regarding the sketches indicate that the adjustments to Open Brush, resulting in the app Mood World (see sec. D.3.3), were suitable and beneficial, and that our custom-built components were actively used by participants. Although using a more familiar system, such as a smartphone or PC, could have ameliorated the usability aspect, interview results (e.g. walking through one's sketch, feeling immersed, forgetting the reality for the moment) suggest that VR offers a unique way of engaging with one's emotions. In this section we first discuss how Mood Worlds supports positive emotions. We then outline design recommendations for VR as positive technology. We then reflect on limitations and opportunities for future work.

D.6.1 Mood Worlds as Positive Technology

Users of Mood Worlds reported feeling empowered, more creative and self-confident after using the application. Thus, they felt success and a sense of mastery. Through providing autonomous self-creation and flexible methods, Mood Worlds allowed them to represent emotions in a corporeal way, either graphically or abstract, and by that it enhanced, amongst other things, their feelings related to people through reminiscence. Participants further imagined different use cases for Mood Worlds. Their ideas ranged from intra- to interpersonal experiences. We hypothesise that interpersonal experiences such as showing another person one's own Mood World could further strengthen interpersonal relationships and foster empathy. Mood Worlds also generated presence and flow while creating them. Our interviews indicate that this in turn resulted in emotional engagement. More precisely, participants felt satisfaction and pride with what they created, awe when being excited "like a child", and happiness and joy when they dived into their personal happy place. Last but not least, Mood Worlds offered room for "taking a break from reality" and offered a space for deep reflection and inspiration for the future, thereby intensifying the purpose in life by re-adjusting the perspective. These aspects show that Mood Worlds successfully addresses each core pillar of the PERMA-theory by Seligman [514], namely accomplishment (success, mastery), relationships (work, familial, romantic, platonic), engagement (flow), positive emotions (happiness, joy, satisfaction, pride, awe) and meaning (purpose). Regarding the aspect of positive emotions, our qualitative results are supported by quantitative findings. The PANAS questionnaire showed a significant increase in immediate positive emotions after completing Mood Worlds.

Besides successfully addressing the PERMA-theory [514], we also assume that Mood Worlds functions as positive technology. Mood Worlds comprises hedonic elements by mediating positive experiences, as shown by the qualitative results. The induction of positive and pleasant emotions [156] could further be shown by significant results in the PANAS. Additionally, interview results indicate a stimulation of reflection and awareness of personal abilities, and an increase in general happiness, which suggest the existence of eudaimonic elements, as well. However, the results of the Oxford Happiness Questionnaire were not significant. As the Oxford Happiness Questionnaire measures happiness on a more general basis, we assume that the one-time intervention Mood World offers might be too short to have a measurable effect on eudaimonic elements (e.g. life satisfaction). To determine potential long-term effects, a long-term study should be conducted.

Further, we found that negative emotions are not significantly altered by Mood Worlds, which was also not intended in our study. Redoing the study when inducing negative emotions would shed light on this aspect. Based on our findings, we hypothesise that Mood Worlds could help processing negative and increase positive emotions.

D.6.2 Considerations for Design

Empowerment was one key finding of the Mood Worlds evaluation, and both a completely unrestricted interaction and offering a pre-defined framework resulted in increased self-reported creativity and self-confidence. Because of the differences in personal preference regarding pre-set options or a completely unrestricted experience, we recommend that VR well-being applications **should provide autonomous design options combined with a pre-defined framework**. We hypothesise that this, in turn, could potentially address the three basic psychological needs, autonomy, competence and relatedness [152]. This will potentially enhance self-motivation and engagement with the virtual experience, which increases the user experience, broadens the target group and frequency of usage [427].

Furthermore, we observed that a moving VE (i.e. elements in motion) also moves the user (i.e. on an emotional level), which can lead to emotional engagement. This refers to the visual content as well as to the desire to move one's body. For the latter, offering unrestricted movement through a cable-free experience (which was technically not possible in our study) would empower people to sit or lie down to further increase their relaxation or to be more physically active and walk through their emotions when feeling excited. Additionally, our findings support the recommendation that VR well-being applications should be **designed so that corporeality of emotions can be expressed in multi-sensory experiences**. Regarding the visual content, visualising emotions in VR seems especially effective when activity and energy of a feeling can be made corporeal. Besides visibly giving emotions a physical form ("corporeal emotions"), applications should include haptic feedback so that users can physically feel the shape [125] and textures [625] of their emotions. Further, applications should increasingly place importance on providing animated options, such as swirling lines that keep on moving after being implemented, or more complex moving entities such as butterflies. We further suggest that VR well-being applications should be designed in such a way that the interaction with elements includes motion of the user. For example, being more or less active in one's body movement could increase or decrease the pace of moving objects or volume and length of music. The latter, through fostering the experience of autonomy, could lead to more creativity [114]. To illustrate, participant 16 envisioned the following scenario:

> You could select how long the melody would play, you do this [draws short line in air with own hand], then, okay, I want the melody to play that long, and if I do that [draws longer line in air] I want the melody that I chose to go for longer. (P16)

Additionally, based on participants implementing and drawing objects reminding them of smell and taste of a specific situation, we further recommend implementing olfactory [341] and gustatory [407] experiences in digital well-being apps. As a starting point for designers, we refer to works by Maggioni et al. [341] for olfactory and Obrist [407] for gustatory implementation possibilities for VR.

Well-being apps and technologies need to meet the high demands of users that feel differently inter- and intrapersonally, depending on the envisioned feeling and situation [433], and different use cases. Apps need to be as applicable for a short break from reality during work (where users just want to forget and relax) as for a longer intervention with the aim to explore and reflect. Effectively, we recommend that VR applications **should be adaptable to personal use cases**. For Mood Worlds, we imagine that an augmented reality application could be developed as a side application to be usable in a lunchbreak, for example, or that a created mood world could be downloaded onto a smartphone for a short glimpse of happiness in a stressful day.

D.6.3 Limitations & Future Work

As a limitation, from our quantitative data we cannot deduce if the significant difference in positive affect felt after completing Mood Worlds can be traced back to the successful AEMT or designing mood worlds. However, results of the interviews strongly indicate that the latter is the case. To study the long-term impact Mood Worlds might have on happiness and well-being, and, second, to measure the influence the feeling of excitement, seeing Mood World as a new toy, has on our findings future work should conduct controlled experiments and longitudinal field studies. Conducting a long-term study could further mitigate the impact that the duration in VR to create mood worlds and the number of sketches could possibly have on survey responses. Although our interviews did not indicate those, we cannot exclude such potential correlations.

While the focus was placed on creating VEs for oneself, multi-personal shared experiences would be interesting to investigate in the future. Research has started to investigate interpersonal distance in VR [469, 597]. It would be, first, interesting to see how friends in contrast to strangers in real-life interact with each other in a virtual sketching environment. Second, it would be fascinating to discover if and how hearing and seeing others affects the user, especially regarding the perceived importance of creating something aesthetically pleasing, felt autonomy and feelings such as childlike excitement. Furthermore, future work could explore the experience of sharing personal mood worlds with friends or family and how this might affect familial social bonds. Additionally, we suggest inquiring the effects of implementing Mood Worlds for negative affective states as well. Our findings demonstrated that Mood Worlds intensifies feelings and that those can last beyond the scope of the application itself. This can be positive when the process of self-designing a VE induces a positive affective state independent of the mood you recreate. On the other hand, this could have undesired effects when Mood Worlds intensifies instead of mitigates negative moods. More research is needed to investigate the relationship between autonomous self-creation and negative affective states.

D.7 Conclusion

This paper explored how the autonomous creation of a VE affects emotional engagement and well-being. To that end, we presented Mood Worlds – a VR application allowing users to visualise their emotions by autonomously creating a VE. Quantitative and qualitative results of N=16 participants showed that Mood Worlds supports emotional engagement and positive affect. Users felt empowered and explored ways on how to give their emotions and energy a corporeal form. Further, Mood Worlds supported them in reflecting on previous positive experiences. We further found that Mood Worlds supports well-being, as defined by the PERMA-theory. With our work we showed that VR can be an effective tool to engage with and autonomously visualise emotions in a VE, thereby increasing positive affect. Our results emphasise the importance of autonomy as a determinant of positive technologies when visualising affective states. We hope that our research provides a starting point for defining the design space of VR well-being support apps.

Acknowledgements

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Part IV

DESIGNING the VIRTUAL SCAFFOLDING

"Even the most self-sufficient of us need a helping
hand to construct the architecture of our
well-being." – Michael J. Fox

Transition

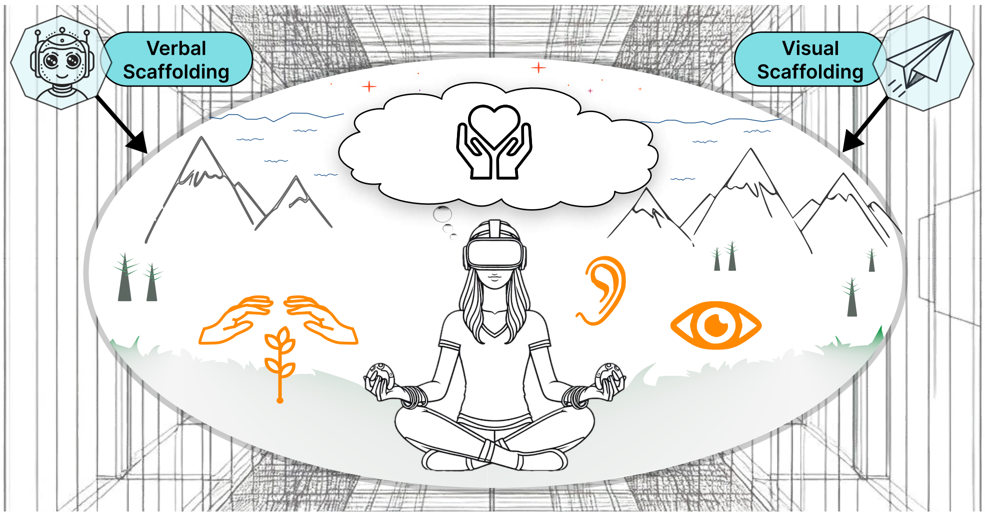

Figure T3.1: Visualisation of the Research Questions: RQ3. This third stage depicts how the virtual space (elements within the ellipse) can be extended by different scaffolding options in VR (elements within the rectangle, highlighted in turquoise) to enhance the effectiveness of self-care practices.

This part, *Designing the Virtual Scaffolding*, explores different ways of extending the virtual space by elements that can guide and support users in their self-care journey. Scaffolding can increase the effectiveness of self-care applications, with the overall aim of fostering mental well-being. This is schematically depicted in Figure T3.1. Part IV consists of two prototypes as presented in papers *E - SelVReflect* and *F - MoodShaper*. Their design is partly informed by related HCI work and partly by findings from our previous publications. This transition will briefly discuss the design decisions that are motivated by our prior research.

Paper *A - AppSurvey* identified a need to address different self-care aspects. Similar to paper *C - VeatherReflect*, paper *E - SelVReflect* focuses on self-reflection and paper *F - MoodShaper* on emotion regulation support. Further, paper *A - AppSurvey* emphasised the need for customisable and unrestricted environments that can be autonomously adjusted, which was tested in paper *D - MoodWorlds*. Our research in paper *D - MoodWorlds* unveiled that our toolkit for self-creating virtual environments successfully achieved several key requirements: it offered the customisation desired by experts, engaged users effectively and can be used to create meaningful safe spaces. Thus, we applied a refined toolset in papers *E - SelVReflect* and *F - MoodShaper* for self-expression.

Additionally, paper *A - AppSurvey* identified a research gap which refers to the requirement of providing support and guidance to identify and reflect upon emotions, providing both a "learning-by-being" and "learning-by-doing" approach. To that end, therapists expect a pairing of such a serious approach with a process that in itself caters to an engaging experience, thus combining psycho-educational with gamified elements. Moreover, papers *C - VeatherReflect* and *D - MoodWorlds* collectively showed that while design can scaffold user interaction to some extent, nudging self-reflection (paper *C - VeatherReflect*) and enhancing creativity (paper *D - MoodWorlds*), participants still expressed the desire for more structured guidance. This was evident from the need for reference points that were voiced by participants, as indicated by the findings in paper *C - VeatherReflect* and feedback about the 'blank page syndrome' experienced in paper *D - MoodWorlds*. Taken together, these findings underscore the necessity to delve deeper into how VR can provide scaffolding to enhance the efficiency of self-care activities, which is explored in detail in this part. Paper *E - SelVReflect* investigates how VR can provide verbal scaffolding, and paper *F - MoodShaper* how it can be leveraged for visual scaffolding, translating therapeutic practice into VR using unique affordances.

Further, in paper *B - Haptics*, our findings highlighted the importance of creating an aesthetically pleasing environment for self-exploration. However, we noted that the environment's simplicity is crucial to avoid distractions. This insight directly influenced the design approach in paper *F - MoodShaper*, where visual simplicity was maintained in the design of emotion regulation strategies. While we also showed that passive haptics can enhance introspection, it must be precisely synchronised with visual inputs. Given the emphasis on autonomy and self-created virtual environments in subsequent studies, this modality was not implemented.

Findings of paper *D - MoodWorlds* further showed how the method of self-creating a virtual environment can be leveraged to create a safe and happy space for users. Thus, we specifically used it in paper *F - MoodShaper* to create a safe and enjoyable space to frame the self-care activity of emotion regulation.

In paper *D - MoodWorlds*, participants also reported enjoying the physical activity of drawing around themselves and being able to duck and physically walk through their self-creations. Inspired by this, we conducted additional interviews with experts, to discern the impact of physical movement on holistic well-being, published as an extended abstract [612]. Therapists clarified that repetitive movement in VR could mirror the process of managing negative emotions as part of a mental well-being strategy. Such an approach generally takes time and repetition to sink in [612]. Consequently, as certain motoric gestures and body postures, such as whole-body movement and standing tall, can facilitate cognitive restructuring [456], we paid more attention to encouraging users to move in VR. Thus, in paper *E - SelVReflect*, we encouraged creating separate spaces that are apart from each other and moving back and forth, and in paper *E - SelVReflect*, all intervention types included movement from participants and needed to be repeated for eight times, to mirror concepts from real-life therapy.

These understandings form the basis of the research conducted in this part, exploring the potential of VR in providing structured support and guidance. Through scaffolding, we aim to enrich the user experience and enhance the efficacy of self-care activities within VR environments.

E SelVReflect: A Guided VR Experience Fostering Reflection on Personal Challenges

Abstract: Reflecting on personal challenges can be difficult. Without encouragement, the reflection process often remains superficial, thus inhibiting deeper understanding and learning from past experiences. To allow people to immerse themselves in and deeply reflect on past challenges, we developed SelVReflect, a VR experience which offers active voice-based guidance and a space to freely express oneself. SelVReflect was developed in an iterative design process (N=5) and evaluated in a user study with N=20 participants. We found that SelVReflect enabled participants to approach their challenge and its (emotional) components from different perspectives and to discover new relationships between these components. By making use of the spatial possibilities in VR, participants developed a better understanding of the situation and of themselves. We contribute empirical evidence of how a guided VR experience can support reflection. We discuss opportunities and design requirements for guided VR experiences that aim to foster deeper reflection.

Contributions: This paper, exploring the impact of self-creation of the virtual environment to reflect on a personal everyday challenge, contributes the following. First, the design and implementation of SelVReflect - a guided VR experience for creative expression and reflection Second, an exploratory evaluation of SelVReflect. Finally, design implications for developing a guided VR experience in which voice-based scaffolding aims to foster reflection.

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Figure E.1: Schematic representation of a user creatively reproducing and reflecting on an emotionally loaded challenge using SelVReflect. The user is guided through voice-based prompts. The figure shows a small section of a 3D drawing done by P8.

E.1 Introduction

Challenging situations in our lives, such as anxiety at work or a stressful family situation, can negatively affect our well-being [1]. Reflecting on these challenges can facilitate understanding, provide new meaning, and improve mental health and well-being [92, 337, 539]. However, finding the (head-) space, time, and resources to effectively reflect on personal challenges can be difficult. Although technologies for reflection exist [195, 539, 299], there is an ongoing need for tools that support users more productively in deconstructing and making sense of everyday problems [3, 266]. Existing technologies for reflection could be improved by focusing more on abstract expression [60] and experiential approaches [3]. There is also scope for a shift in how technology-supported reflective experiences are conceived within HCI, much of which currently utilises reflection as a means to an end, such as improved educational outcomes [48]. Instead, technologies could be designed to actively target reflection as a beneficial activity in its own right [539].

A technology that could cater to users' needs for reflective support is Virtual Reality (VR). Due to its unique affordance to (re)create highly controlled yet immersive environments [329], VR can provide meaningful interventions for well-being [72, 606, 200, 186]. For example, VR can be leveraged to alleviate stress through guided imagery (e.g., [521]), support emotion regulation [373], enhance creative expression in art therapy [90], and elicit positive change in mood, meaning, and interpersonal connectedness [79, 290]. However, few VR applications are specifically designed for everyday reflection [46, 266]. In this paper, we argue that in VR we can leverage unique interactive affordances that go beyond 2D drawing, enhancing the process of expressing and reflecting on personal challenges. VR offers the unique benefits of being able to use dynamic elements in a 3D virtual environment (VE), while the different dimensions can be used to represent temporal or thematic relationships, for example using spatial distancing to represent importance. These can be further explored by physically walking through one's creations and approaching them from different perspectives. Thus, VR offers an exceptional "breeding ground" for an engaging experience, which could lead to in-depth reflection. While Augmented Reality and Extended Reality may offer similar degrees of freedom for expressing oneself, they do not insulate the user from environmental distractions in the same way as VR.

An important consideration when designing VR tools for reflection is to effectively scaffold reflective processes [539] and prevent users from getting stuck in negative emotion cycles (i.e. rumination) [178]. In art therapy, professional therapists guide their clients throughout the reflection process while fostering an atmosphere of creativity, freedom, and playfulness [143, 478]. A challenge, therefore, is to provide comparable guidance for VR experiences that encourage reflection.

To address this, we set out to explore the potential design space surrounding guided reflection in VR. In particular, we investigate how a guided expressive VR experience can be designed and how it can encourage reflective processes. Specifically, our research is guided by the following two research questions (RQs):

RQ_1: How can we design a VR experience that fosters reflection through guided creative expression?

RQ_2: How does our design affect the overall experience and reflection?

SelVReflect is inspired by principles of Positive Psychology and art therapy, leveraging creative expression to make sense of successfully mastered personal challenges (e.g. [343, 90]). Such personal challenges might occur in many everyday life situations, such as in professional contexts or in personal relationships, and can be linked to anxiety, stress, or difficulties with planning, prioritising, or decision-making. All of these challenges could be expressed and reflected on in SelVReflect. We build upon prior research on VR applications which facilitate personal expression by allowing the user to create their own immersive emotional environment through drawing in 3D [609]. SelVReflect also builds upon approaches that scaffold and structure the process of reflection through guiding prompts that encourage users to explore and take on new perspectives [296, 101, 317, 498, 451]. In this work, we focused on voice-based prompts, as they were found to be better suited than visual text-based prompts at enhancing the effectiveness of emotional VR experiences [414] and less disruptive [381, 639], which is critical to consider in the context of immersive self-expression tasks.

First, we conducted an iterative user-centered design process (N=5) consisting of four stages. From this, we derived principles for the design of the voice-based guidance that provides inspiration, encouragement and reflective scaffolding in VR. In the first two stages, the user needs and challenges of performing creative self-expression in VR were identified. In the last two stages, approaches for providing guidance for reflection were explored, including timing, phrasing and the roles the guidance should take on, which were tested in the final part of the design process through enactment. The findings informed the design of SelVReflect, a guided VR experience for creative expression and self-reflection.

To evaluate SelVReflect, we conducted a user study (N=20) where participants visualised and reflected upon an emotionally loaded personal challenge they previously overcame. Overall, our findings suggest that SelVReflect can propagate the discovery of relationships between the components of past challenges. Understanding these relationships can then help identify constructive approaches to personal challenges in the future. This reflective process can evoke positive feelings (i.e. achievement) and support self-efficacy.

This paper contributes the following: (i) the design and implementation of SelVReflect - a guided VR experience for creative expression and reflection, (ii) an exploratory evaluation of how SelVReflect can support creativity, reflection and self-awareness through a user study, and (iii) design requirements for building guided VR experiences that aim to foster reflection.

E.2 Related Work

In this section, we review past research on systems designed to support reflection and define key terms within this area. We then describe previous work in conversational and voice-based interfaces designed to provide guidance and introduce relevant psychological concepts for self-expression, well-being, and positive psychology.

E.2.1 Conceptualising and Designing for Reflection

Reflection can be loosely defined as understanding, thinking about potential courses of action, and one's role within these [511]. Reflection is considered to be helpful [48, 372] as it can offer more self-insight [48], support life changes [554], and benefit health, well-being and personal growth [92, 337, 539]. Yet, reflection can be a challenging activity and often does not occur automatically, but needs to be encouraged [539]. Consequently, designing technology for reflection has become an ever-increasing interest of HCI researchers [195]. Previous work in HCI on reflection has been highly influenced by Schön's framing of reflection [511, 48, 539]. A systematic review conducted by Baumer [48] showed that in 70% of the HCI papers that explicitly define reflection, Schön's notion of reflection-in-action or reflection-on-action was utilised [60]. Reflection-in-action takes place during the action, which means we reflect on our actions while performing them [511]. In contrast, reflection-on-action occurs after an action has finished, in which we use our memories of an event to reconstruct an experience. This effort of stepping back into the experience, retrieving our memories, and organising these fragmented parts is conducted to understand what has happened and to draw out lessons for the future. While this framework offers a useful lens for reflection, it does not directly address how technology can support reflective processes, as remarked by Slovak et al. [539]. As shown by Bentvelzen et al. [61], various strategies have been used in HCI to foster reflection. Through a structured literature review and analysis of mobile applications for reflection, they propose a taxonomy consisting of four design resources: temporal perspective, conversation, comparison, and discovery. While the taxonomy offers a starting point for designing for reflection, it remains unclear which resources (and design patterns) can be used in which context. Therefore, in our work, we explore the use of two of these resources, i.e. *temporal perspective* and *conversation* (with technology), to facilitate reflection on personal challenges.

To assess how well a system fosters reflection, Bentvelzen et al. [61] propose a combined method. Results of a validated questionnaire, the Technology-Supported Reflection Inventory (TSRI) [59], should be combined with a qualitative inquiry, and it should be determined if the system leverages the aforementioned design resources for reflection [61].

Recently, scholars in HCI have started engaging with the intricacies of reflection. For instance, a paper by Eikey et al. [178] highlights a potential risk for reflection-enhancing systems. Certain users of such systems have experienced negative emotional cycles. The authors use the term *rumination* to refer to these cycles and defines it as a counterpoint to self-reflection, in line with Trapnell and Campbell [586]. Eikey et al. [178] further discuss that rumination and reflection are related to a broader sense of the self, also known as self-awareness. While rumination can undermine technology for reflection, it remains an open question of how to balance promoting reflection on the one hand and preventing rumination on the other, which is what we aim to explore in this work.

Multiple systems that intend to facilitate reflection have been designed in HCI for various application contexts [258, 47, 25, 20]. For instance, the web-based application *MoodAdaptor* prompts participants to reflect on positive and negative memories depending on one's current mood [299]. Kocielnik et al. [296] designed *Robota*, a chatbot with voice interaction that aims to stimulate reflection and self-learning in the workplace by asking questions and chatting with the user of the system. A similar approach is used by Jung et al. [270], who designed a conversational agent that facilitate children's reflection as they design mechatronics systems. The agent asks open-ended questions that stimulate a dialogue between the child and the artefact while building the system. In regard to VR, most applications investigate reflection together with another concept, for example empathy skills (e.g. [555]), learning (e.g. [304]), or storytelling (e.g. [29]). Based on a scoping review of twelve VR applications specifically designed for reflection, Jian and Ahmadpour [266] built a conceptual model, named RIOR, that applies a theatrical lens to understand how reflection should be supported in VR. To facilitate reflection, users should mentally prepare before entering VR. Designers can manipulate users' viewpoints in VR, use observational and experiential learning, or include representations of personal items. While the RIOR model offers promising insights, it does not provide recommendations for designing guidance in VR. Furthermore, their model could be extended to examine the case that users design the virtual environment by themselves. Both of these research gaps are addressed in this paper.

E.2.2 Designing Voice-Based Guidance for Reflection

Conversational interfaces, such as chatbots or voice assistants, have been designed to guide users through complex tasks, as they were found to be effective in providing "scaffolds" to thought processes [452, 187, 451, 630]. Furthermore, such systems are shown to be effective for guiding and facilitating reflection with the aim of supporting well-being and mental health [439, 296, 101, 317, 82, 318, 342]. An important question when designing a guide to tie into and scaffold an ongoing task is, in which modality it should speak to the user. Compared to screen-based conversational interfaces, voice-based interfaces are generally considered less distracting [381, 639], making them the more appropriate choice for an application to support creativity and reflection. This is further supported by the study by Kocielnik et al. [296], comparing a speech-based and a text-based agent for the workplace to support employees' activity journaling and self-learning through reflection. Their findings suggest that the voice-based system is easier to use and feels more personal, interactive, and engaging.

When developing a voice-based interface for such purposes, various design decisions, including the agent's voice characteristics (e.g. gender) need to be considered. Research has shown that the identified gender of an agent has an impact on the user's experience [81, 75]. However, previous literature suggests that designing the right voice for an assistant in a given application depends on its context [107, 386, 378, 569]. While real human voices are traditionally utilised [386], other studies suggest that the choice between synthesised and real human voice is context-specific [107]. Previous work also recommends customisation of voice-based agents, as it enhances the user experience [649].

Given this divergent and evolving body of evidence, there is no clear answer on which voice characteristics - such as gender - are most suitable to support an ongoing reflection process. Furthermore, based on the ambiguous evidence on voice characteristics, it is very likely that there are differences in individual preferences. Therefore, we further explore this question through a user-centered design process (UCD) in the context of supporting reflection in VR.

E.2.3 Self-Expression to Support Well-being

Expressing and reflecting on oneself can help people understand challenging events better and give them a new meaning [92, 337, 539]. Similarly, visually expressing and reconstructing past experiences is also used in certain therapeutic approaches, such as art therapy [343]. A foundational theory in art therapy, called the Expressive Therapies Continuum [275], forms the relationships between drawing conceptual meaning using reflective activities and how feelings of positive affect occur through expressive activities. As an immersive medium for artistic expression, VR has also been recently explored as a tool to be administered to patients during advanced stages of art therapy [237, 238]. However, the authors also point out that it is important to have (verbal) guidance in the process of creation.

Creative expression in VR may be overwhelming since not everyone finds it easy to open up and express their emotions [455]. This needs to be considered when designing systems for such purposes. Here, the Dimensions of Emotional Openness model (DOE) by Reicherts et al. [455] can be a useful "predictor" for how difficult a person may find it to perform such a task: People engaging in creative self-expression and reflection (in VR) need to become aware of what emotions they experience and how to internally and externally represent, express, or communicate them. Therefore, it can be assumed that people with lower DOE scores i.e. who are "less" emotionally open will benefit the most from receiving guidance during the expressive process.

E.2.4 Positive Psychology Approaches to Support Self-Efficacy and Behavioural Change

Various psychological and psychotherapeutic approaches, such as goal-oriented psychotherapy [488] or Positive Psychology [515, 627], aim to help people understand how they can cope with challenges by focusing on which of their existing resources they could use to do so. The so-called Agentic Positive Psychology [36] specifically focuses on "mastery experiences", which refer to personal (past) successful behaviours to deal with and adapt to certain situations (e.g. [37]). Such mastery experiences have been proposed as one of the most effective ways to instill the belief in one's own ability to succeed (e.g. in performing certain desired behaviours), and they can lead to positive behaviour change [37]. This is referred to as *self-efficacy* [37]. Self-efficacy can be measured with questionnaires, such as the General Self-Efficacy Scale [508].

Reflecting on past experiences from a positive lens is referred to as *self-modeling* [168]. Self-modeling has been integrated in systems that aim to support positive behaviour change, such as StoryMap [489]. StoryMap is an app that promotes physical activity in families by letting them record, reflect on and share their activities with others. Thus, in addition to the possibility to reflect on and engage with one's own stories (self-modeling), the app also allows users to observe and reflect on other people's behaviour and performance, also known as *social modeling.* Both self-modeling and social modeling were found to help users build attitudes for developing healthy behaviour by positively influencing self-efficacy and outcome expectations.

Here, we aim to build upon and combine these existing therapeutic approaches and interventions, based on the creation of and reflection on representations of successfully mastered challenges. In contrast to Saksono et al. [489] our aim is to build an immersive experience in VR in which participants extensively engage with a past emotionally-loaded challenge through expressive, creative self-modeling. Through this, we hope the user can explore new perspectives on challenges in their life, gain a fresh understanding of them, and discover new ways of successfully dealing with them.

E.3 Design

Our design is inspired by prior literature suggesting that moderately directed guidance helps with reflection [539, 123, 144]. However, we could not directly translate existing (human-human) practices of guiding someone through reflective and expressive activities from creative, educational, or therapeutic contexts (e.g. [343, 176, 453]) to the VR context. VR can immerse people in their creations in a different way, which makes it

Figure E.2: The four stages of UCD to design guidance for SelVReflect with N=5 participants. 1: participants create and experience former challenges to understand own difficulties, 2: participants rewatch the recording of stage 1 to identify opportunities for guidance, 3: participants come together in a focus group to discuss their findings, 4: participants take over the role of guidance to test it.

difficult to predict how existing approaches to providing guidance would translate and how they would "tie in" best into the user's creative process. Therefore, getting users to explore what might work best for themselves appeared to be the most promising approach. This will provide insights in regard to RQ_1.

Thus, we followed an iterative user-centered design process (UCD). The UCD was divided into four stages, which are shown in Figure E.2. The aim was to explore through co-design (i) how the guide should be designed and what role it should take on, (ii) how and when it should appear (within VR), and (iii) the types of guidance and specific prompts it should provide. The same ($N = 5$) participants took part in every stage, which is similar to the average sample size of ($N = 6$) for participatory design at CHI [102]. We invited participants with prior knowledge of VR to reduce the novelty effect, but apart from that we strived for a diverse sample, female: 2, male: 3, age: 27.6 years (min-age: 21, max-age: 31). Two are students, two are PhD-students, one is research assistant. While all were familiar with general HCI research, none of them had previous experience with 3D drawing nor with comparable voice-based guidance systems.

E.3.1 Individual Design of the Virtual Environment

The VE will be created individually by each user. To provide users with the means to conduct a creative expression task in VR, we utilised a 3D drawing tool by Wagener et al. [609]. It offers a palette consisting of various (animated) brushes, animated and static

3D objects, pre-set environments and a colour panel, allowing the user to create their own environment while in VR. Wagener et al.[609] found that this approach of providing autonomy in the design process of a VE - called "Mood Worlds" - accommodates users in visualising affective states and in reflecting on previous experiences by drawing in VR (see Table E.1 elements 1-3). It is thus aligned with our goals for SelVReflect. However, Wagener et al. did not specifically develop Mood Worlds to support reflection, but rather to express positive emotions, i.e. they did not provide any guidance as support for users to reflect (see Table E.1 element 5).

Table E.1: Elements of the Mood Worlds (MW) and SelVReflect (SR) experience.

	Elements of the Experience	MW	SR
1	Choosing a preferred 3D environment	✓	✓
2	Selecting tools/objects from the palette	✓	✓
3	Drawing in the 3D environment	✓	✓
4	Reflecting on one's 3D creation		✓
5	Being supported by guiding prompts		✓

E.3.2 Designing the VR Guidance

We followed a UCD process, which consisted of four iterative stages (see Figure E.2). In *Stage 1: Creating a Personal Experience*, participants were asked to visualise a personal challenge using the 3D drawing tool "Mood Worlds" by Wagener et al. [609]. This experience was to familiarise them with creating emotional environments in VR and to help them with identifying possible hurdles that users might face. The drawing was followed by a short interview (approx. 5 min), in which the researcher inquired about thoughts and ideas behind the drawing to stimulate users' reflection regarding their creation.

The second stage, *Stage 2: Rewatching to Identify Personal Needs*, focuses on identifying opportunities for prompts through watching a screen recording from Stage 1. Whenever participants remembered themselves struggling to express their emotions, they described difficulties and reasons in a template that provided a structure they could follow when taking their notes. They then added ideas on how guidance could have helped at this point, such as an affirmation, inspiration for a new idea, or question for reflection. They also included suggestions for specific wording for those prompts.

Table E.2: Example prompts from the three separate phases of the SelVReflect experience.

Phase	Example Prompt	Purpose
Warm-up	Now think about the main stages of the challenge from the start until the end, when you ultimately overcame it. How many different stages or steps were there?	Suggestions for concrete actions
Free flow	Have you considered how the separate stages might be connected to each other? How could you design these connections? Could they differ? Remember, there is no right or wrong here - as long as you express it in a way that feels right to you, that's all that matters!	Receive inspiration and encouragement for expression and reflection-in-action
Re-walk	Now, focus again on the actions and ideas that helped you overcome the challenge. How did you represent these and how do they tie into the whole process?	Receive thought-provoking questions for reflection-on-action

Stage 3: Discussing & Agreeing on Design Solutions brought all N=5 participants together in a focus group to compare and discuss difficulties and opportunities for guidance. This UCD stage lasted one hour. The focus was placed on *when* and in *which form* (modality, phrasing, voice, etc.) the guidance should be delivered. Apart from the general desire to feel comfortable listening to the voice, there was no agreement on its specific characteristics among participants, such as its gender and degree of human-likeness. When the flow of the open discussion seemed to hesitate, a moderator provided new questions to the discussion, e.g. getting them to think about the role and goals they imagined the guide to play and possess, or how it would compare to having human-driven guidance.

Finally, *Stage 4: Enacting & Evaluating Feasibility* aimed to explore which of the previously identified aspects work well in practice, especially with focus on the guidance types and timing of the guidance. One researcher, who had not experienced the drawing tool before, took on the role of "drawer" and creatively reproduced a challenge in VR. The participants observed and played the role of the guidance by intervening with reflective questions (approx. 20min). Afterwards, the participants and the drawer discussed their insights (approx. 20min).

Each stage further informed and refined the design of the guidance and its prompts for the given usage scenario. Participants wished for a non-embodied guide. As a key reason, they mentioned that feeling watched by a human could negatively affect creativity and the experience, while a virtual guide would act as a facilitator in such a creative self-reflection process. Its role in providing self-support is different from a counsellor providing support, who in everyone's eyes, should be a human. The guide should talk in a reassuring, non-judgmental voice and be available whenever the drawer requests inspiration. As there was no agreement on the voice characteristics, we decided that users should be provided with different voice options.

Identified Phases of the Experience. The four-staged design process revealed that user needs differ and can be categorised into three phases. The guidance, therefore, needs to be designed accordingly. In the beginning, users may feel insecure about how to start with visualising challenges. Thus, guidance should facilitate decisions and help create an image of the challenge in their heads. This would pave the way for getting into a flow state and for empathising with one's emotions. One participant of the UCD (UCD P2) wanted to *"be prompted to then think more abstract and just draw something that works for me"*.

As soon as the drawer seems confident with the system, the guidance should not be as prominent anymore. *"Less is more"* (UCD P5) for this phase, in which a user should get into the flow. However, when progress stagnates, it should remind users to think in abstract ways, to take a new perspective into account or choose another tool. Participants recommended avoiding questions starting with "why", because as UCD P3 pointed out: *"It is an open creative space where people should not feel bad about their creation"*.

After the creation has been completed, the guide could ask if they were happy with their creation and nudge them to physically move around to look at their drawing from different perspectives. Reflective questions were suggested, such as "Think about the situation again. Does your drawing reflect it sufficiently well?".

E.4 Final Prototype

Based on the design process, we created the guidance for SelVReflect. A schematic representation is shown in Figure E.1. As our findings and the previous literature do not provide a clear picture of the preferred gender and degree of human-likeness, participants are able to choose between female/male and human/synthetic voice. By allowing participants to choose their preferred voice, we intended to reduce the risk of feeling discomfort listening to the guidance, which could lead to undesirable effects (confounding factors) on the expressive/reflective task. In line with our findings, we defined three phases for the guided VR experience: (i) "Warm-up", (ii) "Free-flow", and (iii) "Re-walk", in which the guidance inhabits different roles and addresses specific needs. In Warm-up, users will actively request prompts to get started that point out some palette features. In Free-flow, the guide is activated either by the user pressing a specific button on the VR controller or through a longer period of inactivity, indicating that the user is unsure how to proceed. With the help of pilot testing (N=4), we defined that after 30 seconds of either looking at their creation without drawing or placing objects or scrolling through the menu without making a choice, a prompt would be triggered. Deeper reflection questions would only be asked in the Re-walk phase to avoid disrupting the flow.

The guidance addresses key needs identified in the UCD. For the first phase ("Warm-up"), this was to receive concrete actions to get started (i.e. overcoming the "blank page syndrome" and creating a basic structure. For the main phase ("Free flow") this was to receive (i) *inspiration* for new ideas about aspects to express and for using the tools, as well as (ii) *encouragement* to motivate users to continue drawing and to be expressive. For the last phase ("Re-walk") this was to receive thought-provoking prompts to enable in-depth reflection. Table E.2 shows example prompts for each phase of the SelVReflect experience. The list of prompts can be found in the supplementary material. Each prompt contains an inspiration and an encouragement part, for example, *"[inspiration] Have you considered how the stages are connected with each other? How could you design these connections? [encouragement] Remember, there is no right or wrong here - as long as you express it in a way that feels right to you, that's all that matters."* Two researchers reviewed the list of all prompts, merged similar ones, and improved the phrasing to make them clear, non-imposing, playful, and easy to understand. The creation of the final set of prompts was informed by principles used to foster self-reflection, self-expression, and creative flow from the following areas: (1) Counselling [453]: Examples are "What does (thinking of) this situation trigger in you?" and "How does it feel what you are creating here?" (2) Art therapy [343]: Here, questions are often combined with tasks such as creating an image that illustrates how a challenge can be divided into separate components (e.g. "What does this aspect of the image tell you about the challenge?"). (3) Education [176]: Emphasising the need to make learners feel secure, supported and encouraged to take risks (e.g. "What does this aspect of the image tell you about the challenge?"). (4) (Self-)Reflection Research [195]: Guidance should explicitly structure and offer encouraging prompts to review the produced material.

To put our design decision into context, Fleck and Fitzpatrick [195] describe a spectrum of five consecutive levels of reflective thought, ranging from "No Reflection" (R0) to "Critical Reflection" (R4). SelVReflect is designed to facilitate reflection for users to reach at least the "Dialogic Reflection" (R2). To evaluate the actual effects of SelVReflect, we conducted a user study.

E.5 Evaluation

We conducted an exploratory user study with $N = 20$ participants. The overall aim was to evaluate how SelVReflect (for details about its design see sec. E.4) affects users (RQ_2), with a particular focus on the dependent variables POSITIVE AND NEGATIVE EMOTIONS ($RQ_{2.1}$), SELF-EFFICACY ($RQ_{2.2}$) and REFLECTION ($RQ_{2.3}$). We further investigated how differences in emotional openness within our participant sample affect the above dependent variables.

The study received prior ethics approval from University College London.

E.5.1 Data Collection

For each participant we measured the time spent for the drawing phase and the reflection phase separately. Quantitative data was collected from three validated questionnaires. Further, we collected qualitative data through interviews.

Measures

We used the DOE-20 questionnaire [455] to assess participants' affect processing. The questionnaire encompasses five components, including cognitive-conceptual representation of emotions (REPCOG) and communication and expression of emotions (COMEMO). Both traits are relevant for the task of expressing and representing emotions, which participants will carry out in SelVReflect. Capturing REPCOG and COMEMO in our participant sample will allow us to explore how different levels of these traits affect performance and experience with SelVReflect.

We used the PANAS questionnaire [619] to measure participants' affective states before and after using SelVReflect. Participants indicated on a 5-point-Likert scale to what extent they felt a specific emotion (ten positive, ten negative) at that moment. Scores can range from 10 to 50. By using this measure, we can assess if SelVReflect creates positive affect, as can be assumed based on prior research [609, 343]. Increased positive emotions are further relevant as they can co-occur with a sense of achievement and mastery [37]. Moreover, with the PANAS we can measure if SelVReflect increases negative affect. Experiencing negative emotions could be a sign of rumination, one of the risks identified by mental health experts regarding at-home self-care [178]. SelVReflect should prevent rumination and support reflection.

The GSE by Schwarzer and Jerusalem [508] was used to capture the perceived self-efficacy before and after the VR experience (one general factor, good psychometric properties). Participants indicated on a 4-point-Likert scale to what extent they agree with ten items. Scores can range from 10 to 40. Although GSE is designed to capture traits rather than states it has been successfully used for pre-post evaluation of short-term interventions (e.g. [620, 41]). Reflecting on mastery experiences, as is done in SelVReflect, can increase self-efficacy.

After using SelVReflect, we utilised the Technology-Supported Reflection Inventory (TSRI) [59]. This scale specifically addresses how well a system supports reflection. Items 1-3 were reused with the same wording, 4-5 were slightly adjusted to fit the present tool and reflection task (see fig. E.4 for more information) and items 6-9 were excluded, since they were not applicable (as they were related to long-term usage of a system and exchange with other people, which was not part of the present reflective activity).

Interview Protocol

We conducted semi-structured interviews that lasted on average 15 min (min : 08:04 min, max : 24:40 min). Within the interview, we asked participants to elaborate on differences between drawing in VR compared to drawing in 2D, how the prompts made them feel, if and how the prompts changed how they visualised and thought about the challenge, and what they took away from using SelVReflect. The full interview protocol can be found in the supplementary material.

Data Analysis

A one-way repeated measures ANOVA was performed to examine the effect of Time (i.e. pre and post) and DOE Group on Emotions (PANAS) and on self-efficacy (GSE). We further checked for interaction effects of Time and DOE Group.

All audio recordings were transcribed verbatim and imported into MAXQDA software. Two authors both coded four interviews using open coding. Next, a coding tree was established through iterative discussion with all authors. The remaining transcripts were coded individually by one author using the coding tree. A discussion session

Table E.3: Overview of the participant, depicting participant ID, age, profession, prior VR knowledge, the choice they selected in the intervention, the duration of the intervention, and the context of the challenge they chose.

	Age	Gender	Profession	VR Knowl.	Chosen Voice	Duration	Challenge
P1	31	male	Student	minimal	Synth. Male	23 min	studies
P2	23	male	Student	minimal	Human Male	19 min	studies
P3	30	male	Project manager	minimal	Human Female	17 min	work
P4	25	male	Student	minimal	Human Female	21 min	studies
P5	28	female	Scient. assist.	minimal	Synth. Male	34 min	relationship
P6	31	male	Scient. assist.	extensive	Synth. Female	21 min	studies
P7	31	female	Scient. assist.	occasional	Human Male	18 min	work
P8	32	female	PhD student	minimal	Human Female	22 min	relationship
P9	32	male	PhD student	extensive	Human Male	10 min	work
P10	25	female	PhD student	occasional	Human Male	22 min	studies
P11	27	female	PhD student	minimal	Human Female	34 min	studies
P12	27	male	PhD student	minimal	Synth. Male	18 min	work
P13	26	male	PhD student	minimal	Synth. Female	28 min	work
P14	28	non-binary	PhD student	occasional	Human Female	36 min	studies
P15	27	male	IT specialist	minimal	Human Female	35 min	friends & fam.
P16	24	male	PhD student	minimal	Synth. Male	28 min	friends & fam.
P17	29	male	PhD student	occasional	Synth. Female	33 min	university
P18	26	female	PhD student	minimal	Synth. Female	14 min	friends & fam.
P19	53	male	Scient. assist.	minimal	Human Female	31 min	work
P20	27	female	PhD student	minimal	Human Female	20 min	studies

between the two main co-authors was conducted to identify themes using thematic analysis [83]. Those were discussed and agreed upon in a final discussion round between the two main authors and additional two co-authors, who were experienced in psychology and reflection research.

E.5.2 Participants

We used our extended social network and snowball sampling to recruit participants. In total, $N = 20$ (7 females, 12 males, 1 non-binary); see also Table E.3 for more details) participants took part in the study ($M = 29$ years, $min: 23$, $max: 53$). They received remuneration of an equivalent of 12€ in the respective currency. Participants were recruited from four research labs within different domains and from industry. Participants self-indicated that they felt mentally stable and healthy at the moment of participation. Most participants had limited experience with VR (14 have used it a couple of times or less and 3 people on a regular basis). In DOE-20, our participant sample had scores similar to the reference values for DOE, indicating "normal" affect processing: for REPCOG ($M = 2.26$, $SD = 1.11$) and COMEMO ($M = 1.89$, $SD = 1.10$) versus the reference values [455, 87] of REPCOG ($M = 2.42$, $SD = 0.77$) and COMEMO ($M = 2.01$, $SD = 0.82$). Participants' combined REPCOG-COMEMO score was used to form two groups, one with an elevated (upper half) and one with a lower (lower half) capability of representing and expressing emotions, which we will refer to as HI-EMO and LO-EMO. The two groups will be used to investigate how emotional openness affects the dependent variables (PANAS, GSE, and reflection).

E.5.3 Study Set-up

The studies were conducted in a 35m² lab and lasted 1h 26min on average (min : 55 min, max : 1h 50 min). The application was developed in Unity and run on an Oculus Quest 2 using AirLink. The VE was created by the participants themselves, using the toolkit tested for emotional expression from Mood Worlds [609] (see sec. Section E.3.1 for detailed description and Table E.1, element 1-3). An additional component was added for the voice-based guidance, delivering the separate prompts when requested by the user (through the VR controller), or based on the user's behaviours (i.e. 30-second inactivity thresholds). A detailed description of the design and implementation of the prototype can be found in sec. E.4.

E.5.4 Procedure

Similar to Prpa et al. [440], we chose an exploratory study design. After giving consent and sharing demographic data, participants completed the DOE-20, PANAS and GSE. Participants then started a tutorial phase, in which they familiarised themselves with the tool's functionality. Afterwards, they were asked to choose their favourite voice (human/synthetic and female/male) for the guidance. While the experimenter set up SelVReflect with the chosen voice guidance, participants were asked to recall and write about an emotionally loaded challenge they had successfully overcome. This approach is based on the Autobiographical Emotional Memory Task (AEMT) [262]. Then, they created a representation of the challenge, its stages and the emotions attached to each stage using SelVReflect. During that, they either requested guidance or it would be proactively provided in case of inactivity. Towards the end, the guidance would ask reflection prompts, inviting participants to "experience" their creation again and approach it from different perspectives. They could choose to think aloud at that moment. When finished, participants filled out PANAS and GSE again. Additionally, they answered the reflection scale TSRI and questions specifically designed to assess their experience with SelVReflect as well as the guidance they received while using it. The study ended with a semi-structured interview.

E.6 Findings

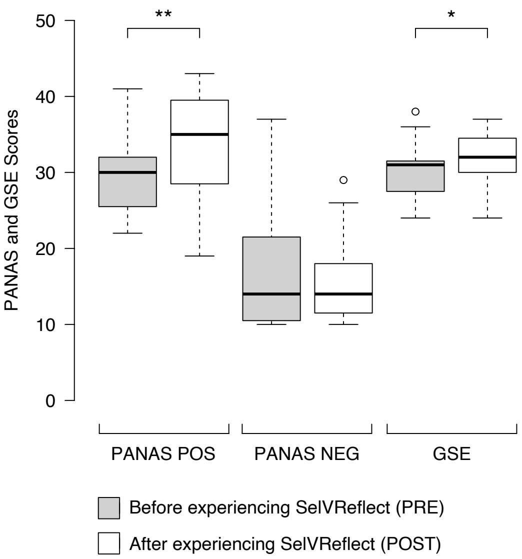

Figure E.3: Mean scores for pre and post measurements of PANAS (positive and negative) and GSE scales. Significant results are indicated with * for p<0.05 and ** for p<0.01.

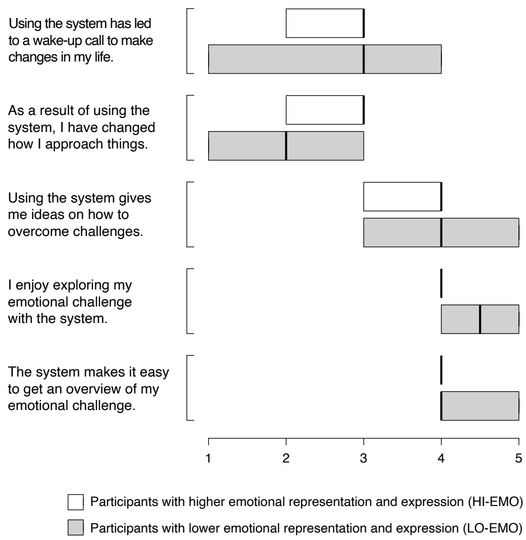

Figure E.4: Median ratings and interquartile range for the first five items of the TSRI scale. They are split up for HI-EMO and LO-EMO groups.

Based on the evaluation, we gathered quantitative results from the questionnaires, as well as qualitative insights from the interviews. Our findings will be presented in this section.

E.6.1 Quantitative Findings

Based on visual inspection of our data and the Shapiro–Wilk statistic we could not assume normally distributed data. Therefore, we applied the Aligned Rank Transformation (ART) [634]. Due to a misunderstanding in the task instructions, one participant was excluded in the analysis. When examining participants' choices of the

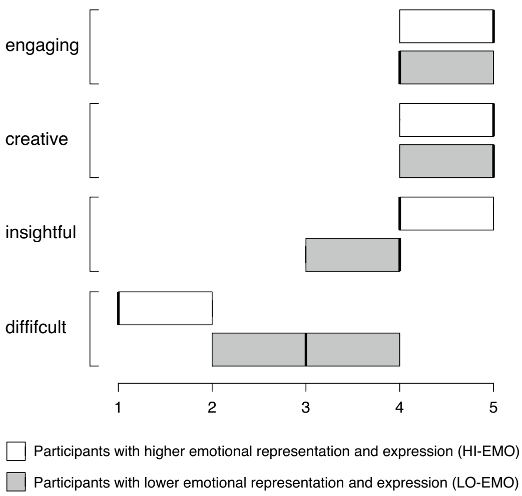

Figure E.5: Median ratings and interquartile range for the ratings for the experience of using SelVReflect, split up for HI-EMO and LO-EMO groups.

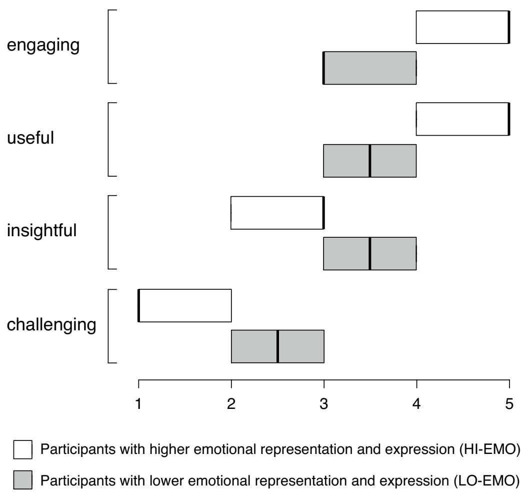

Figure E.6: Median ratings and interquartile range for the ratings for the guidance received, split up for HI-EMO and LO-EMO groups.

available voices using descriptive statistics, we found that the *human female* voice was chosen 8 times, while the other voices - *human male, synthetic female, synthetic male* - were all chosen 4 times. Participants received a prompt approximately every $M = 92s$ ($SD = 33s$).

Emotions (PANAS)

The one-way repeated measures ANOVA showed a significant effect of Time on Positive Emotions $F(1, 17) = 10.720, p = .004$ (see Table E.4 and Figure E.3). We found no significant interaction effects of Time and DOE Group $F(1, 17) = 0.335, p = .570$. We did the same analysis for Negative Emotions (PANAS). The test showed neither a significant effect of Time on the Negative Emotions $F(1, 17) = 0.446, p = .513$ nor an interaction effect of Time and DOE Group $F(1, 17) = 1.998, p = .176$.

Self-Efficacy (GSE)

We conducted another one-way repeated measures ANOVA with Time on *GSE* $F(1, 17) = 6.189, p = .024$ showing a significant effect (see Table E.4 and Figure E.3). Again, we found no significant interaction effects of Time and DOE Group $F(1, 17) = 1.224, p = .284$.

Table E.4: ANOVA statistics for PANAS and GSE scores for factors TIME, DOE-GROUP, TIME DOE-GROUP. Statistically significant results are marked with asterisks ($* < .05, ** < .001$).

Factor	PANAS Pos.	PANAS Neg.	GSE
TIME	$F = 10.720$	$F = 0.446$	$F = 6.189$
	$p = 0.004$**	$p = 0.513$	$p = 0.024$*
	$\eta^2 = 0.387$	$\eta^2 = 0.026$	$\eta^2 = 0.267$
DOE-GROUP	$F = 0.998$	$F = 4.781$	$F = 2.041$
	$p = 0.332$	$p = 0.043$*	$p = 0.171$
	$\eta^2 = 0.055$	$\eta^2 = 0.220$	$\eta^2 = 0.107$
TIME:DOE-GROUP	$F = 0.335$	$F = 1.998$	$F = 1.224$
	$p = 0.570$	$p = 0.176$	$p = 0.284$
	$\eta^2 = 0.019$	$\eta^2 = 0.105$	$\eta^2 = 0.067$

Reflection (TSRI)

When considering how participants rated the reflection they engaged in while using SelVReflect, neutral ratings were given to the first two items related to (1) making changes in one's life ($Md = 3, SD = 1.305$) or to (2) the ways in which one approaches things ($Md = 2, SD = 1.170$), as can also be seen in Figure E.4. High ratings were given for item (3) the extent to which the system gives ideas to overcome challenges ($Md = 4, SD = 0.994$), (4) the enjoyment of exploring the challenge ($Md = 4, SD = 0.911$), and (5) the ease of getting an overview of the challenge ($Md = 4, SD = 0.946$). Figure E.4 divides those results further into participants with higher and lower capability of representing and expressing emotions.

Exploratory Analysis of Experience Ratings

When asked about the experience with SelVReflect, participants gave it positive ratings along various dimensions (on a Likert scale from 1 to 5), including how engaging ($Md = 4.5$), creative ($Md = 5$), and insightful ($Md = 4$) they found the experience. When considering these ratings from the HI-EMO and LO-EMO groups separately, they are generally very similar, as can be seen in Figure E.6. However, LO-EMO ratings for difficulty were lower ($Md = 3$) than for HI-EMO ($Md = 1$).

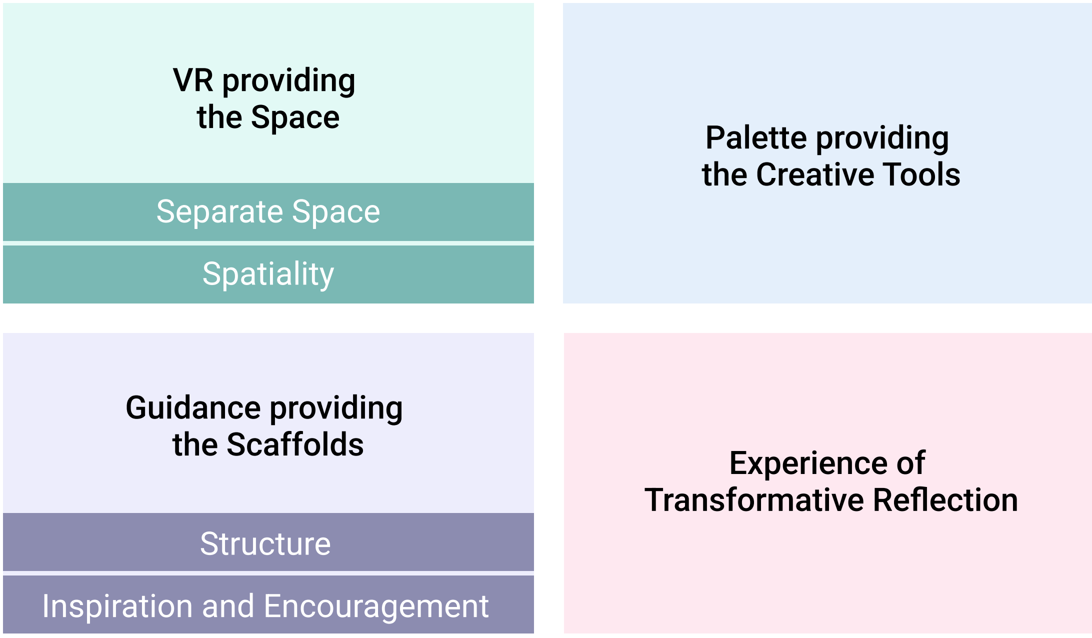

Figure E.7: Thematic map of four themes and codes identified in the semi-structured interviews.

When participants rated the received guidance, it was also highly rated for how engaging ($Md = 4$) and useful ($Md = 4.5$) it was. The guidance was given a rating of $Md = 3$ for how insightful it was. Again, the ratings from the HI-EMO and LO-EMO are very similar (see Figure E.5). However, there was a more noticeable difference in the ratings for how challenged they felt by the guide in their process of expression and reflection, with LO-EMO participants $Md = 2.5$ versus HI-EMO $Md = 1$.

E.6.2 Qualitative Findings

Based on our qualitative inquiry, four themes were derived from the data: *VR Providing the Space*, *Palette Providing the Creative Tools*, *Guidance Providing the Scaffolds*, and *Experience of Transformative Reflection* (see Figure E.7). Our findings are described below and illustrated with excerpts from the interviews.

Most of the chosen challenges were related to participants' studies in University (9) or work settings (6), while the remaining (5) were related to friends and family or romantic partners (see also Table E.3). Five out of the latter were about deciding on how to allocate time between different friend groups, family, or work. Six challenges were related to interpersonal difficulties as part of studies (e.g. group projects, theses) or professional settings. Four challenges dealt with approaching a major decision (e.g.

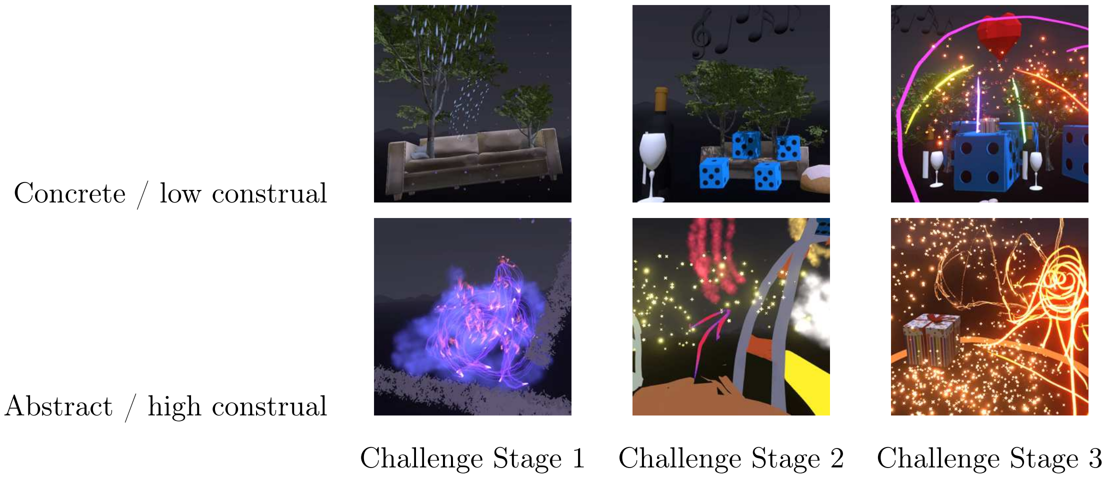

Figure E.8: Two exemplary SelVReflect drawings (above: P4 below: P11). The first row depicts a concrete representation of a challenge. Trees and dice stand for different friend groups (stage 1), sharing an evening together (stage 2), becoming friends (stage 3). The second row depicts an abstract representation. Uncertainty and anger represented with blue smoke, plasma and fire (stage 1), transitioning from mud through smoke by going up a ladder (stage 2), joy of overcoming the challenge in bright colours (stage 3).

switching jobs or moving homes) and three were related to adjusting to a new situation or setting (e.g. a new home or job).

VR Providing the Space

The first theme focuses on the specific benefits of VR for facilitating creativity and reflection. It encompasses the codes *Separate Space* and *Spatiality*.

Participants reported that being in VR enabled them to enter a different "mind-set". Most participants chose a mostly black (standard or space) environment as a backdrop for their creation, because it provided a "stark contrast" to the university lab space where the study was conducted. A key reason was that VR offers a *separate space* without external disturbing factors, which allowed them to dive deeper into their thoughts. VR can facilitate the experience of flow, to *"almost get lost in whatever you drew, whatever the image you created"* (P5). One participant elaborated on the benefits of VR:

> You're like cut off from everything. You're like in this empty void. It helps a lot of people to be with their thoughts and explore them more because they're cut off and for themselves. (P9)

VR also allowed participants to utilise the virtual 3D space to express components of their challenge beyond what would be possible in physical reality. For example, they used the third dimension as representation for time or they link the relationships between components of their challenge, as 3D drawing *"makes it easier to show correlations between several things"* (P7).

Further, they utilised the *spatiality* of VR to immerse themselves in, as well as physically, mentally, and emotionally distance themselves from different elements (of their challenge). On the one hand, they enjoyed being surrounded by their creation, exploring their emotional challenge environment through a first-person perspective. This allowed participants to enclose themselves within their drawings, break through their drawings, and become more physically involved in the depiction of their challenge.

> "You can actually 'paint yourself in', completely all around you, if you like, and take up different positions." (P13)

Although 2D figures cannot convey the feeling of being cornered by ones' own drawing, or physically moving through a wall when overcoming a challenge, we have provided previews in Figure E.8. On the other hand, participants also enjoyed being able to taking a literal 'step back' from their drawings. This change of perspective led to another experience of the emotions and enabled them to see the whole picture, which sometimes made the problem seem smaller than before.

> I just recognise kind of the third person perspective on your decisions, so putting yourself not in your shoes, but just having a bird's eyes view. There might be something that is interesting and is now more tangible with having done it yourself [in 3D]. (P16)

However, for some the blank space surrounding them created a feeling of being lost, and not knowing where to start. On a similar note, some participants found it challenging to "think in 3D" when drawing and to utilise the complete space available for their creation.

Palette Providing the Creative Tools

As a second theme, we found that the variety of tools provided the means for creative self-expression and reflection. Most participants emphasised that using the palette increased their motivation, and made them think in a more abstract way, so that "visual elements [are used] as a sort of analogy or metaphor" (P19). Objects were mainly used as placeholders for people (see Figure E.8) or abstract constructs, such as loss of agency (e.g. dice), personal growth (e.g. tree) or emotions (e.g. fire for anger). Animated brushes were often used to represent emotions and relationships between components. For one example of abstract representation, see Figure E.8. One participant clarified:

> I feel like the choice of tools was surprisingly wide enough to try out different things and also to, yeah, express more complex emotions. (P5)

However, this availability of choice was also a limitation for some participants. Roughly half of the participants reported difficulties in choosing a tool, especially at the beginning. As well as some (technical) problems with actually drawing or resizing objects, four participants reported difficulties in identifying emotions, and eight participants were unsure how to visualise them with the provided tools.

Guidance Providing the Scaffolds

The third theme encompasses the reactions to and effects of the voice-based guidance participants were offered throughout the study. We present the codes *Structure* and *Inspiration and Encouragement*.

The guide provided *structure* by encouraging participants to decompose their challenge into smaller stages, which in turn structured their thinking of the challenge's process. Overall, participants' reported feeling reassured by this guidance. Participants emphasised the importance of feeling inspired and encouraged by the spoken prompts. This was due to both their content, which led them to approach components differently, and their tone: *"it's not just about what they say, but how they say it. It helps you relax and ease into it"* (P9). This led them to think in greater detail about the challenge they were depicting. Furthermore, their self-confidence was strengthened by both the tone of the voice and the affirmations it offered. P8 further summarised:

> I really loved the guide. [...] In taking the time to dissect the situation where I was in, I think that really helps also because it made me feel more confident about what I did. It [the guidance] supported me in looking back on it [the situation] and seeing it from multiple perspectives, probably more than what I thought about so far. (P8)

Nevertheless, more than half of the participants expressed a desire for more context-aware guidance. This includes more individual timing and content-specific questioning towards aspects of their creation, e.g. intervening at a specific moment when an important choice was made. They also desired more specific help and inspiration with how they could visually represent specific elements of their emotional experience (e.g., in the form of symbols, visual metaphors etc.).

Experience of Transformative Reflection

Participants reported that they reflected *"along the way" (P15)* by decomposing the challenge, abstractly visualising their emotions, and adding details. This was especially prominent during the Free-Flow phase. In the Re-walk phase, while (re-)experiencing their creation, some participants reported that they felt stimulated by the prompts prompting deeper reflection, while others were less affected. However, all (N=20) agreed that they were successfully reflecting at some point during the SelVReflect experience.

Taking up the opportunities for reflection, participants approached their challenge and its (emotional) components from different perspectives. This led to a change in their conceptualisations of the following:

1. The challenge itself. They gained new (or deeper) knowledge about the reasons behind the challenge, the emotions involved, and their role within the process (e.g. *"It's an even deeper engagement with the situation [in contrast to writing it down]" (P19); "I thought more about what kicked it off" (P9); "It's a sense of accomplishment, a sense of resolution, also a sense of closure." (P5)*).

2. Themselves as a person. This encompasses self-awareness about one's character, one's beliefs, and one's role within the social ecosystem. They also felt proud of themselves (e.g. *"That was actually a realisation that I never had before: That talking to people and the opening up and not always trying to solve things by myself, which is what I do now, [is healthy]" (P8)*).

3. The bigger picture. Participants appreciated their relationships to their friends more than before, discovering alternative approaches or solutions to their challenges, such as thinking in stages, which made them feel better equipped to act more effectively in equivalent scenarios in the future (e.g. *"It [SelVReflect] is a possibility to reflect on certain problems, especially also from an emotional point of view, and to find other approaches and therefore to be able to adapt one's behaviour better"* (P13)).

We want to emphasise that the experience of SelVReflect did not evoke the same level of reflection in all participants. However, even when no perspective change was reported, participants felt reassured by and comfortable with the system.

E.7 Discussion

In this work, we set out to explore the potential of a VR experience that fosters reflection through guided creative expression **(RQ1)**. To answer this question, we developed SelVReflect through an iterative design process. It facilitates the expression of and reflection upon personal challenges within a VR environment. Provided with an eclectic palette of tools, the users created their own virtual environment, assisted by a voice-based guide that encouraged and supported their abstract expression and motivated them to reflect. We further examined the effects of SelVReflect on the overall experience of reflection **(RQ2)**. We conducted a user study (N=20) in which we tested our approach within the context of reflection on personal challenges. We found that SelVReflect was perceived as an engaging, creative and thought-provoking experience, which had a significant effect on positive affect and self-efficacy of participants. Our findings further indicate that the experience was more difficult for participants with lower affect processing scores compared to those with higher scores - however, despite differences in difficulty, both reached similar outcomes.

In this section, we discuss our main findings and show how SelVReflect relates to and extends existing research. We then outline design recommendations for supporting expressive and reflective tasks in VR. Finally, we discuss limitations and ways forward.

E.7.1 Reflecting on SelVReflect

SelVReflect has been specifically designed to cater for deep reflection (see Section E.4), thus addressing a need discussed by Baumer et al. [48] and extending approaches explored by Wagener et al. [609]. To evaluate whether we achieved these goals, we measured reflection through a combined method, as proposed by Bentvelzen et al. [61]. First, we used the TSRI [59], which indicates that a high level of reflection was evoked. Second, our system actively leverages two design resources. It utilises *Temporal Perspective* by triggering past memories of an emotionally loaded challenge, and the guidance to help users dive into' them more deeply. The guidance also encouraged users to engage with internal and/or think-aloud "conversations" with themselves. As a third assessment [61], we conducted a qualitative inquiry. All ($N = 20$) participants mentioned aspects that fit to existing conceptualisations of reflection in literature. Some reported discovering new constructive approaches for challenges [195], gaining (self-)awareness [346] (such as general self-knowledge of how to deal with problems, their relationship with friends), developing new understandings and appreciation [80] (such as about reasons for the challenge and appreciation of relationships to friends), and feeling empowered or better equipped for the future [376]. We also found no evidence of rumination. On the contrary, qualitative findings indicate an active prevention of rumination as SelVReflect motivates the user to reflect "through" *continued* expression and guidance [586]. Hence, we can confirm that our approach for a guided VR experience actively supports reflection, answering RQ2.

However, the levels of reflection [195] that users reached through SelVReflect differed - some participants' reached level 1 (Reflective Description), while others progressed to level 2 (Dialogic Reflection). While some felt confirmed in their previous perspective on the challenge, others discovered new ways of how they could approach them more effectively in the future. This suggests that transformative reflection took place. Discovering new ways of dealing more effectively with challenging situations is closely related to self-efficacy. Self-efficacy was significantly increased through using SelVReflect. Participants who did not reach higher levels indicated that (i) it might be because they had already reflected extensively on the given challenge, (ii) the chosen challenge would not allow for more discovery, or (iii) because they do not reflect a lot in general. Applying the RIOR model by Jiang and Ahmadpour [266] (for more information see Section E.2.1) could possibly support users in achieving level 2. Adding further functionalities to SelVReflect, such as importing personal photos could help deepen the reflection further. However, this should be carefully considered as it could lead to very different types of expression than the abstract ones SelVReflect is currently designed for.

E.7.2 Design Recommendations

Based on our findings, we discuss design recommendations for designing VR-based interventions that aim to foster reflection in creative open-ended tasks. We will discuss three specific design recommendations relevant for the HCI community.

In our research, we encountered that users were often confronted with the fear of facing a blank page or canvas [478]. Upon seeing the empty space around them, experiencing the sometimes overwhelming degrees of freedom, and not knowing how to visualise a challenge, some participants were uncertain how to proceed (e.g., [237, 238]). This can inhibit users from entering a state of flow [143]. Guidance can and should create a reassuring atmosphere, a 'framework of freedom' as Rubin [478] calls it. In our case, guidance can mitigate the negative feelings of feeling lost. Thus, especially in the beginning, guidance could be provided rather frequently. Besides talking in a calm and reassuring voice, that is preferably chosen by the users themselves beforehand to reach the best effect, the guidance should provide encouraging prompts similar to approaches from art therapy [143]. To overcome the first stage of blockage or insecurity, we found that more specific *prompts*, such as *"Choose a suitable colour and type of brush that match your feeling and then colour the space around you where you are currently standing"* were most promising. They break down the task into smaller ones to help the user take a step forward. In the "Free-flow" phase, the frequency of the prompts should decline and the context should shift towards theme-based prompts. As an example from our work, each of our prompts was formed by an *inspiration* part, prompting users to think about other topics (e.g. how people were involved, how to connect the phases) and an *encouragement* part. The latter has the aim to give users self-confidence and addresses the need for encouragement for meaningful reflection as proposed by Fleck and Fitzpatrick [195] and Slovák et al. [539]. In line with research showing that human guidance can facilitate flow [143], we propose that voice-based guidance can cater for the same in an exploratory open-ended VR experience. Towards the end of the experience, we found that users have more head-space to process deeper reflection questions than when they were still in the process of creating. The guidance can be used here to provide such questions, e.g. *"Now, focus again on the actions and ideas that helped you overcome the challenge. How did you represent these and how do they tie into the whole process?"*.

Overall, we found that reflection can be successfully supported in-action and on-action with a single intervention [511]. However, we have also shown that guidance for reflection has to constantly adapt to the evolving user needs throughout the whole process. This mirrors findings from personal informatics, in which reflection is also described as a dynamic process over time [60]. Based on these aspects, we recommend that guided VR experiences for reflection should:

Recommendation 1—Provide guidance adjusted to users' changing needs over time, starting with "hands-on" suggestions for specific actions and ending with more high-level reflection probes.

Our findings also revealed some insights into how drawings were made (see Figure E.8), about thought processes and the effects of in- and on-action reflection. We found that SelVReflect successfully guided the visualisation process by inspiring and encouraging users. SelVReflect was specifically designed, using VR as medium, a tool palette as means, and voice-based guidance, to cater for autonomous expression. In particular the encouragement part of the guidance has the aim to give users self-confidence and addresses the need for encouragement for meaningful reflection [195, 539]. However, SelVReflect is also designed to provide restrictive scaffolding, to reign in the free flow of expression so that users can actively reflect [539].

As can be seen in the participants' drawings (see Figure E.8), participants visualised the challenges in concrete and more abstract ways. As an artifact mirroring participants' thoughts, one can deduce that different mental representations prevail. Participants further reported developing a more structured thought-process, discovered new relationships between components of the challenge, formed new conceptualisations of themselves, and gained appreciation of how these insights may help them in the future. As an understanding lens, we take the Construal Level Theory (CLT) [587] into account. CLT has inspired work on personal growth, well-being and reflection in HCI (e.g. [60, 396]). It describes that when thinking about a situation on a low construal level, thus in a concrete way, users place the focus on the 'how' of the activity. In turn, higher construal and more abstract mental representation show a focus on the 'why' and indicates a greater psychological distance towards the challenge. Related to SelVReflect, we found that a guided VR experience for reflection should support both forms of construing information: On an interpersonal level, some participants need to be prompted to think more abstract or more concrete to gain deep insights. On an interpersonal level, some participants need to be prompted to think more abstract or more concrete to gain deep insights. On an intra-personal level, and taking the fear of facing a blank page or canvas [478] into account, systems should motivate operating on a low construal level, especially at the beginning of the process, then the system can change the focus and promote conceptualising situations in a higher level of construal. Although SelVReflect seems to succeed in this task for most users, e.g. by using objects to represent complex constructs such as loss of agency, there is still more research and development needed to fine-tune the experience. As an example, adding context-aware prompts and individually-adapted guidance beyond what SelVReflect can currently provide, seem to be promising next steps. Generally, we propose that guided VR experiences for reflection should:

Recommendation 2—Provide encouragement to think and express oneself in an abstract way while providing context-aware scaffolding to facilitate reflection.

We designed SelVReflect to provide users with a fertile (virtual) ground for transformative reflection, leveraging space, means and guidance to support this. As established in previous research, effective reflection benefits from structured support and encouragement [195, 539]. However, as Agapie et al. [3] emphasise, deep reflection also requires effort, which can decrease the enjoyment of the task itself and lead to a loss of motivation to persevere. In addition, excessive scaffolding can also decrease the level of creativity in reflection and reduce the potential for lasting transformation. The risks of hindering reflection can be mitigated when autonomy and joy are a central focus of the design.

Hence, to inform designs striving to guarantee transformative reflection, systems should place careful attention not to detract from their sense of autonomy and self-actualisation. To be more precise, systems should strike the right balance between motivating users to reflect and allowing "breathing room" for joy and playful expression. Our findings emphasise the importance of free choice and the benefits of step-specific guidance that withholds from authoritative statements to guarantee creativity, flow and playful expression. Thus, we recommend that guided VR experiences for reflection should:

RECOMMENDATION 3—Provide *reflective "stimulation"* instead of *instructions* to facilitate reflection.

E.7.3 Limitations and Future Work

In this section, we discuss the limitations of SelVReflect. Although we carefully designed SelVReflect, paying special attention to the timing of prompts, the guidance still interrupted some participants in undesirable ways. In particular, subsequent prompts were triggered prematurely for those who took more time in selecting colour hues. Although some commented on this during the interviews, it was usually not disruptive to the general flow, although not helpful for reflection in those cases. As Reicherts et al. [452] discuss, the key reason for prompts not being perceived as disruptive can be due to the nature of an open-ended and/or creative task.

Furthermore, we could not compare experiencing SelVReflect to a control group using another pre-existing application, as it offers a completely new technology-supported experience. For instance, it goes beyond translating art therapy into VR, extending previous research in this regard (e.g. [237, 238]), combining drawing with other components such as sound, three-dimensional environments, light, animation and (user) movement [609], and providing voice-based guidance specifically designed for expressive reflection in VR, forming a new experience altogether. Consequently, it is challenging to identify a valid baseline to compare the prototype with. Given the novelty of this experience, it is thus more meaningful to first explore how and what it enables users to create and discover, as we endeavoured to understand in this work. Nevertheless, based on the exploratory evidence generated in this study concerning the interplay between the key constructs (e.g. relationship between guided, expressive reflection and self-efficacy), future studies on similar tools could further formalise them as hypotheses as part of an experimental design. In our study, we also empowered users to choose a comfortablesounding voice, as research suggests that preference for gender or human-likeness varies on an inter- and intrapersonal level, and is context-specific [107, 386, 378, 569]. Yet, the identified gender of an agent can influence the user experience [81, 75]. Although in our study it was more valuable to make users comfortable with the guidance (and reduce potential confounding factors, e.g. due to discomfort), we gave users the option to choose their preferred voice (and it was thus included as a "feature" of SelVReflect). However, future work could extend our research and investigate the effects of gender, tonality and human-likeness on expression and reflection in a controlled experiment with separate conditions.

Additionally, we did not check for the reflective capacity of the participants beforehand, as suggested by Bentvelzen et al. [59]. Instead, we focused on how the expression of emotions would affect reflection. As the ability to express one's emotions is tightly linked with participants' affect processing, we chose to assess their representation and expression of emotions, as measured by the DOE-20 [455]. Still, we advise future studies to include a measurement of reflective capacity, e.g. through SRIS [59], as this could reveal interesting insights into how people who reflect less may benefit more from SelVReflect. We also want to point out that we tested SelVReflect mostly with people with tertiary education. While reflective capacity develops with age and also within an educationally stimulating environment [375], it also varies among individuals and it cannot be deduced that reflection capacities are lower in lower educational levels. Nevertheless, we cannot assume that our findings apply to everyone across social groups and socioeconomic status without further research.

Further, three participants emphasised the risks of SelVReflect when used in a more therapeutic setting, e.g. as a tool to deal with ongoing and unfinished challenges. However, one participant also emphasised the opportunities of exploring such unfinished challenges despite certain constraints of the current system: (*"A lot of challenges that came to mind are still in this destructive phase. That's why I think it would have been exciting to do that. But I would probably have missed things, like the world bursting into flames." (P7)*). This shows how SelVReflect can trigger the desire in some users to deeply and extensively express themselves and their emotions, and how it can be approached as part of an intervention with multiple, continued applications. It appears plausible that the creative reconstruction of past events can positively impact and facilitate transformation at a later stage. However, while this highlights our approach's potential to be useful in other fields, such as emotion regulation and problem-solving, this was not the focus of our research. We want to emphasise that the effects of using systems similar to ours for self-care approaches - in particular for unfinished challenges

- remain unclear and need to be carefully researched, to investigate the psychological effects and potential risks when being able to set the VE "bursting into flames". Although mental health experts see the benefits of at-home self-care, they also emphasise the risks of getting stuck in negative emotion cycles [178]. They are concerned that negative feelings might increase when exposed to and immersed in strong negative emotions without professional guidance [606], which suggests that more research is needed on how VR applications should be specifically designed to support people to cope with negative emotions. However, it is necessary for us to point out that, while findings of SelVReflect indicate an active prevention of rumination, these results can only be supported for our specific setting. Thus, future studies should revisit this topic and test SelVReflect with professionals.

E.8 Conclusion

To provide a novel way to reflect, we created SelVReflect - a guided expressive VR experience to foster reflection. Through a user-centered design process (N=5) and a mixed-methods study (N=20), we showed how this experience could lead to new insights into past challenges and oneself through drawing in the three-dimensional space. SelVReflect enabled participants to draw connections between the different components of past challenging experiences, (re-)approach them from new perspectives, and in some cases even helped them identify (new) constructive ways of approaching similar challenges in the future. Furthermore, the quantitative analyses revealed that expressive reflection in VR is not only considered highly engaging and insightful but it also enhances positive affect and self-efficacy. In sum, there seems to be promise in building VR experiences for reflection in which users can freely express themselves while also having the chance to receive inspiring and encouraging guidance. However, to strike the right balance between autonomy and scaffolding guidance requires careful crafting of the timing, content, and phrasing. We hope our work and design recommendations inspire designers and researchers to further explore this promising research field.

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F MoodShaper: A Virtual Reality Experience to Support Managing Negative Emotions

Abstract: Negative emotions such as sadness or anger are often seen as something to be avoided. However, recognising, processing and regulating challenging emotional experiences can facilitate personal growth and is essential for long-term well-being. To support people regulating and reflecting on negative emotions, we designed MoodShaper — a VR experience where participants autonomously create a virtual environment combined with ER interventions. Our system included three different interventions designed based on expert interviews with psychotherapists. We evaluated MoodShaper in a mixed-method between-subject study with $n = 60$ participants. Participants experienced one of the three ER interventions, allowing them to manipulate visual representations of negative emotions through either externalisation, seclusion, or appreciation. We found that MoodShaper significantly increased positive affect while decreasing difficulties in ER and negative affect. Our work demonstrates how VR can provide technology-mediated support to reflect on, engage with and manage negative emotions. We contribute insights for future VR systems which support ER for challenging situations.

Contributions: This paper, exploring the impact of self-creation of the virtual environment paired with visual metaphoric interactions with that environment on emotion regulation, contributes the following. First, the design and implementation of MoodShaper – a VR experience for creatively expressing and visually managing negative emotions. Second, an exploratory evaluation of MoodShaper. Finally, design implications for designing VR-based self-care applications that aim to support practising emotion regulation strategies for managing negative emotions.

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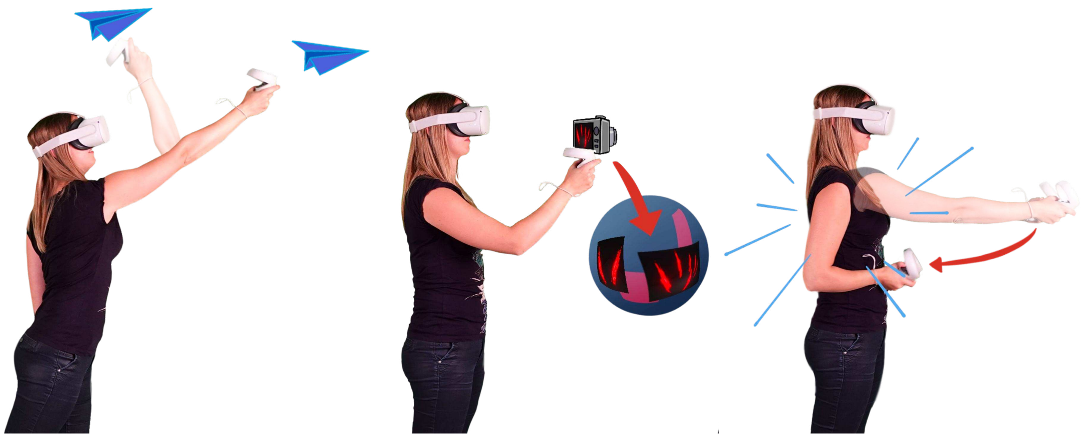

Figure F.1: MoodShaper encompasses three interventions for managing emotions, manipulating the visual representation of a previous drawing that visualises negative emotions. In *Launch Paper Planes*, users throw away paper planes; in *Frame a Picture Globe*, they take pictures of their drawing which then appears in a globe; in *Shine Your Light*, users pull their drawing depicting negative emotions towards them and start to sparkle.

F.1 Introduction

Negative emotions, such as anger, frustration, jealousy, and sadness, are often thought to be emotions that should be avoided. Research suggests that persistent engagement in repetitive negative thinking patterns, such as overthinking and rumination, can significantly impair mental health, contributing to increased levels of stress and anxiety [178, 213, 570]. Relaxation [582, 636, 546] and physical exercise [122] can potentially mitigate negative emotions and rumination, as can actively recognising, processing and regulating emotions [232, 230, 621]. However, often external support is needed to develop effective coping strategies to regulate and reflect on negative emotions. Many people turn towards digital solutions for autonomous mental health management in their everyday routine [128, 542, 604]. Here, 'everyday routine' refers to non-clinical settings, acknowledging that while clinical environments play a crucial role in mental health care, they represent a different context from the daily life settings where these digital tools are often used and that are the focus of our inquiry. Although digital technologies cannot substitute treatment by experts [128], they can offer new possibilities to help people practise coping strategies, such as consciously altering thoughts to change emotions [542, 604].

Among various tools for such contexts, Virtual Reality (VR) stands out as particularly promising. It allows for controlled yet immersive environments [330], blocking out distractions from the real world. It provides excellent potential for customising the 360° space to match personal preferences, allowing for creative expression through dynamic elements and metaphoric actions that are not possible in reality (e.g. [89, 225]). The approach of addressing negative emotions with VR treatment in Human-Computer Interaction (HCI) research has been studied in manifold cases, such as through adapting the VR setting (e.g. environment or lighting [331, 603]), or by confronting users with their fears in exposure therapy [365]. Others aim to uplift one's mood, teaching relaxation techniques [582, 636, 546], or providing mindfulness training [387, 333, 607]. Some therapeutic interventions also teach strategies to manage emotions directly [228, 373], e.g. teaching cognitive restructuring [308]. However, most of these interventions are meant for clinical use (e.g. [229, 308]), require substantial training and/or psychotherapeutic expertise (e.g. [365]), depend upon additional tangible objects (e.g. [607]), or focus on creating positive affect without supporting the user to cope with negative emotions (e.g. [636]).

Hence, there is a need for VR applications that support untrained users in regulating and reflecting on common negative emotions, providing self-care at home. Notably, two examples should be mentioned: Grieger et al. [225] studied coping with negative thoughts triggered by textual messages. Yet, their approach requires technical knowledge and focuses on specific negative thoughts instead of general everyday negative emotions. Wagener et al. [612] identified design requirements for VR interventions that support the processing of negative emotions. However, they explore the topic theoretically, based on interviews with therapists, and without implementation or user testing.

Thus, we introduce *MoodShaper*, a VR application designed to offer technologically-mediated support for managing everyday negative emotions. It allows users to autonomously create a virtual environment with the purpose of expressing emotions, then, employing one of three interventions aiming to manage and regulate emotions by providing means for users to manipulate visual representations of negative emotions in VR.

As suggested by HCI literature [540], MoodShaper is grounded in psychological theory, including aspects of positive psychology [290], metacognition therapy [109], ER strategies [228, 229, 360], and is based on principles of art therapy, leveraging creative expression to manage negative emotions (e.g. [343, 90]). Further, it is inspired by two theoretical frameworks. The first, proposed by Slovak et al., is used to situate our application [540], as MoodShaper is a VR application intended to provide unrestricted and unguided at-home self-care (e.g. no additional guidance provided by clinicians), targeting individuals who perceive themselves as mentally healthy and well-balanced who are interested in developing and practising ER skills. Further, we envision that, in the future, this system or a similar one, might be used by people who struggle with mental health challenges. The role of MoodShaper is to provide experiential practice, both when experiencing negative emotions in the moment ('on-the-spot' relief [540]) and when reflecting on a past emotionally charged situation ('offline' training based on own memory [540]). The second framework is by Wagener et al. [612]. They established design requirements and four design concepts together with psychotherapists to support independent self-care with VR, is used to inform the design of MoodShaper. In brief, all three interventions for managing negative emotions promote the externalisation process [446]. Inspired by Wagener et al. [612], they (i) offer complete closure by allowing negative emotions to dissipate symbolically in a peaceful manner (*Launch Paper Planes*), (ii) compartmentalise emotions to reduce their salience, distancing from them in a detached mindful way [623] and spatially confining them to not feel overwhelmed (*Frame a Picture Globe*), and (iii) invite users to radically accept negative emotions [325] and reframe them [308] as useful, to develop resilience and self-growth (*Shine Your Light*). A schematic overview of the developed interventions is presented in Figure F.1. MoodShaper is tailored to deductively learn emotion regulation (ER) strategies through the metaphoric use of its interventions alone. In other words, the vision of this work is to extend the design space of technology-mediated ER support in VR, expanding the "room for manoeuvre" when engaging with (challenging) emotions to diversify in-situ and offline options for untrained at-home usage.

To evaluate MoodShaper, we conducted a hybrid user study involving $n = 60$ participants in a remote and laboratory setting. The study aimed to provide initial insights, within one session, into the emotional impact, ER capabilities, overall engagement, and experiential outcomes associated with ER interventions in VR. Our findings showed that all three interventions significantly increased positive affect, encouraged self-reflection and elevated a sense of control. We conclude with a set of implications to inform the future design of VR applications for independent everyday self-care through managing negative emotions to improve user well-being.

This paper contributes the following: (i) the design and implementation of *MoodShaper* – a VR experience for creatively expressing and visually coping with negative emotions, (ii) an exploratory evaluation of how MoodShaper can support managing emotions, and (iii) design implications for constructing VR experiences that aim to support practising ER strategies for negative emotions.

F.2 Background & Related Work

In this section, we define key terms within the area of psychology and ER, with a particular focus on strategies for managing emotions such as emotional expression and cognitive restructuring. We then review past work on VR applications aiming to provide support when managing emotions.

F.2.1 Managing Everyday Negative Emotions

Emotions are complex and elicit diverse definitions and a multitude of strategies for their management. Negative emotions are mostly defined as being unpleasant to experience, expressing negative affect towards an event or a person, linking negative emotions with a negative outcome [322]. Many emotion theories, such as Russel's Circumplex Model of Affect [438], mirror this definition and categorise emotions based on their valence (positive-negative) and arousal or intensity (high-low). However, other research argues that the polarity of emotions is misleading due to the complexity of emotions [544], instead highlighting the positive aspect and utility of feeling so-called "negative emotions" such as sadness or anger [422]. As a source of information [507], negative emotions can help recognise threats and handle potential danger [183] and can be motivating for self-growth [242]. Still, dwelling too much on negative emotions can potentially lead to entering repetitive negative thought cycles, also called rumination [213]. Rumination disburses stress hormones and increases the stress response circuit [399], can result in harmful coping behaviours such as overeating or excessive alcohol consumption [487, 213], and can contribute to the onset of depression [260] while prolonging the time it takes to recover from negative experiences [570]. Consequently, managing negative emotions is essential for one's mental health and well-being.

F.2.2 ER Methods: Emotional Expression and Cognitive Restructuring

Managing emotions is commonly referred to as Emotion Regulation (ER) [228, 360]. ER encompasses all (un-)conscious processes that affect one's emotional responses in order to achieve an appropriate mode of functioning and well-being [78, 229]. Most ER strategies aim to regulate the intensity, duration, and/or quality of emotions, particularly negative ones, through methods such as selective attention to aspects (situational attention), changing perspectives (cognitive reappraisal), or controlling emotional reactions (response modulation) [621]. While numerous methods to practise ER exist, two methods are of particular importance for this paper, artistic emotional expression [228, 279] and cognitive restructuring [206, 308].

Emotional Expression is used in different therapeutic approaches, particularly art therapy [343]. Artistic activities such as drawing or role-play help externalise emotions [240, 228], facilitating sense-making and fostering emotional control, self-regulation, and subjective well-being [279, 426]. Engaging in the process of expressive activities can increase positive affect [275]. Yet, creative expression using interactive technologies such as VR without additional therapeutic guidance may be overwhelming since not everyone finds it easy to open up and express their emotions [455]. Thus, there is a need to carefully design engaging experiences.

This paper also draws inspiration from cognitive change methods, specifically *cognitive restructuring* [206, 308]. Cognitive restructuring, also known as reappraisal or reframing, varies slightly across therapies. In this paper, we adhere to the definitions used in metacognitive therapy (MCT) [109, 624]. It involves re-evaluating one's thoughts, promoting flexible thinking and perspective changes. Cognitive restructuring can reduce rumination and negative emotions [624], and improve general mental health [206, 232, 360, 308]. While numerous methods for cognitive restructuring exist, here, we briefly define some pertinent ones: *Externalisation* teaches individuals to detach from problems, negative thoughts, and emotions [446]. For instance, within therapeutic practice, people can be taught to think that they are not defined by sadness but that sadness may occasionally manifest within them. *Metacognitive reframing* encompasses empathic perspective taking, taking an observing role, or using the socratic dialogue as methods [624]. *Detached mindfulness* describes choosing not to worry about an aversive thought, instead allowing the thought to occupy its own mental space [623]. Detached mindfulness, similar to radical acceptance, involves tolerating negative emotions without judgment, avoiding simplistic positive/negative divisions of emotions [115, 325].

However, visually expressing emotions and cognitive restructuring often rely on skill sets such as self-reflection, planning, and goal setting [88], which can be challenging to master without external support. To mitigate, a tangible manifestation of negative thoughts and emotions can help the externalisation and metacognition process. For example, Brinol et al. [88] found that materialising and objectifying thoughts or emotions and discarding them in real life, for instance by writing them on a piece of paper and throwing it away, supports the mental process of cognitive restructuring [89]. Additionally, necessary distance for externalisation and taking on an observer's role was found to be exemplified using photography [374]. Further, research found that certain motoric gestures and body postures can facilitate cognitive restructuring as well [456].

We specifically target the practising of ER methods, particularly emotional expression and cognitive restructuring, applying them to VR and evaluating their impact on users.

F.2.3 VR for Managing Negative Emotions

In recent years, many also turn towards digital solutions for regulating emotions in their everyday routine [128, 542, 604]. However, many tools are not originally employed for ER [542] such as smartphones [477, 528], videogames [599], social media [70], and online shopping [93] and the potential of specialised technologies in supporting ER remains largely unexplored in HCI [537]. Further, Slovak et al.[540] criticise that most systems do not rely on theoretical grounding from psychology, and prioritise information conveyance over the actual development of ER skills, as this requires an emotionally charged but secure environment that many cannot provide.

To address this gap, we ground our interventions on psychological ER methods, and use VR to generate emotionally charged environments. In that regard, VR has emerged as a powerful tool for inducing and managing emotions, as it can evoke visceral responses akin to reality [240, 331] through a sense of "being there", called presence [462, 433, 603]. Immersive spaces in VR isolate users from real-world distractions and afford complete control [330], encouraging users to dedicate focused time to engage with their emotions, unlike augmented reality or conventional 2D conversation- or paper-based interventions. Despite being costlier, VR offers unique interactive features, enhancing emotional expression and cognitive restructuring. For example, dynamic elements in a 3D environment boost motivation, confidence, and creativity, even for those lacking artistic talent in real life [609, 611]. Additionally, VR enables spatial perspective-taking which can facilitate empathic understanding [185], a challenge in real life [300, 622].

These affordances are often leveraged to induce positive emotions for change [290], mindfulness [440, 607], relaxation [435, 459], and stress management [521], as well as negative emotions for exposure therapy [365], in art therapy [237, 238], and for managing negative emotions [331, 373]. However, if not carefully designed, VR has the potential to re-introduce trauma and induce rumination [606]. To render VR effective for ER, personalised content in VR is of uttermost importance [28]. An illustrative case of personalised emotional content are self-created emotional islands to visualise valence in a multi-user VR setup [516]. However, this research does not teach ER strategies. Another example is the work of Grieger et al. [225], who empower users to physically engage with personal negative text messages, allowing them to release frustration and transform their thoughts through punching and trashing those messages. Yet, Grieger et al. [225] have focused on investigating negative thoughts in response to certain text messages rather than exploring negative emotions as a broader spectrum, and technical knowledge how to implement these messages in VR is essential. On another note, Wagener et al. [612] have explored VR interventions for ER in a holistic way, and have developed a set of design principles for VR interventions aimed at facilitating the coping of negative emotions in a self-care setting. However, they solely explored the topic conceptually, drawing insights from interviews with therapists, but without implementing their findings in VR. Therefore, in our work, we seek to address these research gaps. We introduce MoodShaper and conduct a user study in VR in which we evaluate carefully designed coping mechanisms for negative emotions in everyday life.

F.3 MoodShaper

MoodShaper is a VR application intended to provide unrestricted and unguided at-home self-care both when experiencing negative emotions in the moment (in-situ [540]) and when reflecting on a past emotionally charged situation (offline [540]). Thus, MoodShaper caters to unguided and untrained individuals interested in developing and practising effective ER strategies for future use and to those seeking immediate relief from negative emotions. The application is designed to be used by individuals who perceive themselves as mentally healthy and well-balanced, as well as those who might struggle with mental health challenges. Nevertheless, we restricted participation in our study to mentally stable users, due to our ethical responsibility to avoid potential risks for vulnerable users as we evaluated the prototype. Given this diverse and individualised usage, the design of MoodShaper has to be carefully crafted. Thus, it is inspired by existing literature and grounded in established psychological theories, as recommended by Slovak et al. [540]. The design rationale will be explained in detail in this section.

To support people in regulating and reflecting on negative emotions, prior HCI literature has shown that it is beneficial to use personalised environments [28, 433, 606]. For example, psychotherapists have recommended that VR applications aiming to support mental health and well-being should provide customisable options, including colours, shapes, and objects that have personal meaning for the user [606, 612]. As such, prior work (e.g. [293, 605, 609, 611]) has already used adapted versions of the 3D drawing application OpenBrush [1], providing a tool palette facilitating autonomous expressive drawing as used in art therapy (e.g. [343]), but adapted for use in VR. Thus, *MoodShaper provides personalised content of VR experiences for emotional expression.*

[1] https://openbrush.app/. Tilt Brush, now called Open Brush, was made open source by Google in 2021 on GitHub.

When envisioning VR applications that support ER strategies, therapists also emphasised the importance of movement, becoming active and feeling empowered, as physical exertion can support cognitive engagement [612]. As such, therapists appreciated the idea of repetitive movement to engage users physically. Additionally, prolonging the interventions can also mirror the process of managing negative emotions in real-life therapy, which takes some time [612]. Further research found that certain motoric gestures and body postures, such as whole-body movement and standing tall, can activate a sense of power and can facilitate cognitive restructuring [456]. Hence, *the interventions in MoodShaper are repeated eight times and could foster a whole body movement.*

Additionally, related work has shown the benefits of the objectification of negative emotions for ER [88, 89]. They found that materialising and objectifying thoughts or emotions and discarding them in real life, for instance by writing them on a piece of paper and throwing it away, supports the mental process of cognitive restructuring [89]. Adapting this concept to VR, Grieger et al. [225] have designed physical representations of negative text messages in VR that users were able to trash or punch for ER purposes, showing a positive shift in thoughts and emotions through the objectification. As such, *the interventions in MoodShaper allow for manipulating objectified representations of negative emotions.*

To foster reflection, we leverage the concept of physical and spatial perspective-taking. Previous work showed that physical and spatial perspective-taking (e.g. examining a drawing or an object from various angles), correlates with empathic perspective-taking and can change one's mental state [185]. Further, it can facilitate reflection and stimulate novel insights [611]. This approach has been elucidated by therapists [612] and confirmed in analogous studies using OpenBrush for contemplating personal challenges [611]. Thus, in each intervention, users have to manipulate visual representations of negative emotions from eight different perspectives, effectively either turning once around themselves (360°) or physically moving around their drawing to interact with it from eight different angles. Therefore, *MoodShaper is designed to facilitate physical and mental perspective-taking.*

Moreover, Wagener et al. [612] postulated that VR emotional regulation applications should always begin and conclude with positive elements, thereby rewarding users for their engagement in ER and instilling a sense of accomplishment (i.e. "Full Circle Concept"). Thus, *MoodShaper will end on a positive note.*

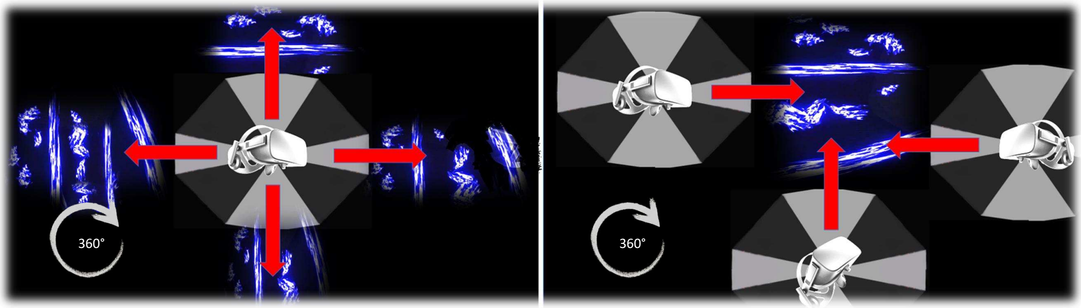

Figure F.2: Schematic top-down view of the indicator on the floor. The light grey segments indicate the direction in which the user still needs to turn in order to interact with the representation of the negative world. The dark grey segments do not have brushes stored (any more). The left figure shows the option in which the user has drawn around themselves, leading to a 360° turn of the user. The right figure shows the option in which the user has drawn in front of them, leading to the user walking 360° around the drawing to interact with it from different perspectives.

F.3.1 Final Prototype

Combining all the aforementioned design decisions, we designed MoodShaper. Users leverage a tool palette for 3D drawing, consisting of nine pre-set environments to choose from, which offers twelve (non-)animated brushes, and a colour panel that can be utilised to create what we call "worlds" in VR. This tool palette in MoodShaper is used to create two contrasting worlds: a positive world that represents happiness and enjoyment, and a negative world that embodies negative emotions.

In the intervention phase, users are required to perform interactions (such as launching paper planes, framing a picture globe, or assimilating the world and shining one's light. The design of these interventions are based on therapists' conceptualised ideas [612], for more detailed information, see the following sections). All of these interventions result in the gradual dissipation of the representation of the negative world, which disappears gradually when users interact with their drawing. To explain the technical background, the space around the user is divided into eight segments (see schematical representation in Figure F.2). During the creation of the negative world, the system records the segment in which the participant draws. It is important to note that, due to the limitations of OpenBrush, these stored segments are relative to the user's viewpoint at the time of creation. Therefore, if the user executes a 180° turn and then returns to the original viewpoint, the segment on the user's reverse side stores these brushes. This limits the interactions to a maximum of eight. Further, users have to rotate once around themselves or physically move around the drawing to engage with it from different vantage points. This is schematically represented in Figure F.2. To facilitate this process and ensure comprehensive coverage, we have integrated a visual floor indicator. Light grey sections on the indicator signify the required turning direction, which transitions to dark once the correct orientation is achieved and the interaction is performed (see schematical representation in Figure F.2). On a side note, we carefully balanced repetitive movements alongside the gradual disappearance of drawings through preliminary testing. This is to ensure cognitive engagement and visual change without compromising efficacy of ER methods, e.g. through tiring arms. Effectively, the intervention phase was intentionally shorter than VR world creation. Post-test interviews confirmed our design, providing adequate time for ER without becoming burdensome.

After using the intervention and all painted segments have disappeared, the initially self-created positive world reemerges ensuring that MoodShaper ends on a positive note. This step brings the experience full circle (compare [612]) and serves as a reward and relief for participants, who were thus not prior informed about the re-emerging of the positive world.

Launch Paper Planes

All interventions are inspired by conceptual suggestions by therapists who shared their ideas of VR interventions for managing negative emotions [612]. They are thus building on their extensive experience and commonly employed ER techniques in psychotherapy. The three interventions are depicted in Figure F.3.

The first intervention - called *Launch Paper Planes,* abbreviated to *Launch* - is based on an ER technique in which clients label balloons or paper planes with negative thoughts or emotions and release them into the sky [612]. Through this, they externalise negative thoughts and mentally and physically distance themselves from them, performing a symbolical closing gesture [612]. *Launch* follows ideas also used in externalisation narrative therapy, metaphorically helping clients to separate themselves from problems, negative thoughts and negative emotions they are facing [446]. In line with prior work ([89, 225]), *Launch* uses objects (paper planes) as visual proxies to represent negative emotions. However, we decided to visualise a less "forceful" or aggressive object manipulation such as punching or burning them as was tested in prior work (e.g. [89, 225]). Releasing negative thought patterns in a peaceful manner was emphasised by therapists [612], and can also be found in VR meditation and relaxation games that target feeling peaceful and free (e.g. ReMind VR [1]). This is further in line with prior HCI

[1] https://store.steampowered.com/app/862220/ReMind_VR_Daily_Meditation/

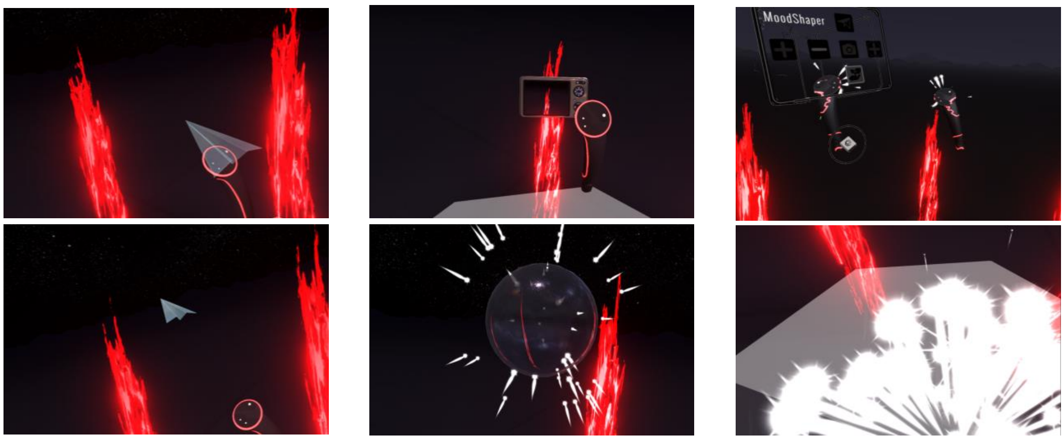

Figure F.3: MoodShaper encompasses three interventions: (a) Launch Paper Planes, in which paper planes are attached to a controller that are launched in the sky, (b) Frame a Picture Globe, in which users take pictures of the negative emotional world with a camera attached to the controller and those pictures then appear in a picture globe, and (c) Shine Your Light, in which users extend their arms, and pull them towards the own body while using the trigger buttons. After succeeding, users emit a burst of sparkling light.

research emphasising the need to design interventions for ER in a careful way to avoid re-introducing trauma and mitigating the risk of rumination (e.g. [606]). Hence, this intervention uses paper planes that were launched into the sky to externalise and find complete closure through peacefully releasing negative emotions.

Frame a Picture Globe

Similar to *Launch, the second intervention - Frame a Picture Globe, abbreviated to Frame - follows ER methods of externalisation [446], separating oneself from the emotions, but emphasises the metacognitive therapy techniques of detached mindfulness [623]* In contrast to leaving negative emotions behind completely, *Frame* revolves around packaging and storing negative emotions in a specific secluded spot. Based on Wagener et al.'s framework [612], the assignment of a specific space for negative emotions allows users to create an appropriate distance, while supporting reflection by enabling them to re-visit those spaces again. This intervention aims to strengthen the idea in users that distancing from one's emotions and spatial perspective-taking can reframe one's thought pattern and facilitate empathic concern [185]. Further, we draw inspiration from photo art therapy and phototherapy [622], in which photography is used in art therapy as the camera creates beneficial distance between photographer and subject [300]. Effectively, through this distance and through the mechanical nature of taking pictures, photographers can regain a sense of control and possession over feelings, ordering internal chaos and reducing the power of traumatising memories [300]. In their role as photographers, participants can also gain confidence as they are often more familiar with photography than painting which reduces the emotional and personal involvement when creating the photograph, again creating necessary distance [139]. Thus, in this intervention, a camera is attached to the main controller, and users take pictures of their VR drawing from different angles.

Further, this intervention aims to emphasise to users that emotions sometimes can be better dealt with when manifesting them in a tangible form [89, 374]. Effectively, each picture taken with the camera gradually removes part of the drawing representing negative emotions, and the disappearing parts reappear as a picture within a globe that is in front of the user. As with all interventions of MoodShaper, after the repetition of the intervention for eight times, the positive world previously created by the user reappears. While in *Launch* and *Shine* nothing of the negative world perseveres, here we follow principles of metacognitive therapy, specifically detached mindfulness [623], emphasising that negative emotions should not and cannot overwhelm us but are allowed in their own (somewhat restricted) space. To mirror this idea, the *Picture Globe* encapsulating the negative world is still visible in the positive world: users can pick up the *Picture Globe*, place it somewhere or look again inside it to deal with the negative emotions again and reflect on them as desired by therapists [612]. Hence, this intervention uses a camera to create emotional distance between user and their negative emotions, to regain power and confidence, and negative emotions recorded in pictures are stored in a manifested 3D object to represent the notion of detached mindfulness.

Shine Your Light

The third intervention - *Shine Your Light,* abbreviated to *Shine* - draws on principles of radical acceptance [325], acknowledging and tolerating all negative emotions without judgement and accepting the reality as a grey area instead of black and white thinking [325]. Instead of denying the existence of negative emotions or trying to avoid feeling them, people should welcome the complexity of all emotions [544] due to their helpful nature [507, 422], which can form fertile ground for self-reflective development and self-growth [242, 612]. Therapists emphasised welcoming all emotions, including the negative, due to their important role in forming fertile ground for self-reflective development and self-growth [612]. In that regard, users shift their view of negative emotions as something undesirable to something focused on facilitating positive transformation, resilience and self-growth, drawing on principles of reframing [109] through re-interpreting the emotions. To visually represent these concepts, users pull the negative emotions towards them, assimilating them into themselves. After each performed gesture, the user emits a burst of white and sparkling light, which gradually increases in intensity over time, as a sign of positive transformation and increased resilience and self-growth.

F.4 Evaluation

MoodShaper has been evaluated through an exploratory hybrid VR study with $n = 60$ participants. Following suggestions by Ratcliffe et al. [448] and as MoodShaper targets VR users seeking everyday in-situ and offline ER support, we conducted the study remotely in participants' homes, allowing them to be comfortably alone with their feelings. The study set-up varied for remote participants (see Section F.8). However, to ensure a diverse participant sample, including those with little or no VR experience, we also offered the option to participate in a laboratory setting. Laboratory studies were conducted in a room-sized $4m$ by $7.5m$ ($30m^2$), using the Meta Quest 2 with AirLink wireless connection to allow free movement. Similar to other related works (e.g. [225, 440, 516, 611]), we adopted an exploratory approach as comparing to conventional baselines introduces several confounding factors: Comparing with mobile phone applications for ER (e.g. [477, 528]) would limit autonomy and movement possible in 3D spaces, VR approaches by Semsioglu et al.[516] lack ER support and focus on multiplayer settings, and Grieger et al.[225] offer ER strategies limited to regulating negative thoughts in a forceful way, not everyday emotions. Further, many VR ER systems require technical knowledge and time to prepare [591], making them incomparable to our objectives. The study received prior ethics approval from [blinded for review]. The overall aim was to evaluate how MoodShaper can support ER, affect, user experience and user engagement, with a specific focus on exploring the different interventions. This section first presents how we collected and analysed the data. We then introduce our participant sample and procedure.

F.4.1 Data Collection

Quantitative data was collected from four different validated questionnaires. Further, we gathered qualitative feedback from participants to understand their experience with MoodShaper.

Measures

PANAS We used the PANAS questionnaire [619] to measure the affective states of users before and after creating the negative world and experiencing the ER intervention. Participants indicated on a 5-point Likert scale to what extent they felt ten positive and ten negative emotions at that moment. By using this measure, we can assess if MoodShaper creates positive affect, and reduces negative affect.

S-DERS We used the S-DERS questionnaire [314], containing 21 statements, to measure participants' ER capabilities before and after the intervention. It focuses on short-term factors such as interpersonal experiences and situational influences, assessing nonacceptance, modulation, awareness, and clarity on a 5-point Likert scale. Scores range from 21 to 105; higher scores indicate more difficulties with ER, and lower scores post-intervention suggest improved coping strategies facilitated by MoodShaper.

UEQ-S We used the UEQ-S questionnaire [501] to measure user experience of the interventions. Participants rate eight pairs of attributes on a 7-point Likert scale, assessing pragmatic (usability and utility) and hedonic (joy and stimulation) qualities. The questionnaire helps determine if the interventions are user-friendly and enjoyable, as low scores could undermine the effectiveness of the ER interventions. Scores range from -3 to +3, with higher values indicating a superior experience.

UES-SF We utilised the UES-SF questionnaire [406] to assess user engagement with the interventions. Participants rated 12 items on a 5-point Likert scale, assessing averaged scores for aesthetic appeal, focused attention, perceived usability, reward factor and the overall score. Higher values indicate greater perceived engagement and active involvement, potentially fostering reflection [49, 195].

Interview Protocol

We conducted semi-structured interviews averaging $18:56$ minutes (min: $8:30$, max: $34:57$). Participants discussed their reflective capacities, emotions, and thoughts during the study, focusing on their interpretation of the intervention and their experience with MoodShaper. Additionally, they viewed demonstrational videos of the other interventions to gather initial reactions. The full interview protocol is available in the supplementary material.

Data Analysis

For our quantitative analysis parametric tests were used, since only validated scales were employed (PANAS and S-DERS) which have previously also been tested parametrically [35, 205, 172, 395]. This fact, combined with cell sizes larger than five, allows for reliable parametric analysis, as recommended by Norman [403]. *Pre* and *Post* measurements were analysed using paired t-tests. A one-way ANCOVA was conducted with *Post* measurements for all subscales as dependent variable and factor *Intervention* with *Pre* measurements of the respective subscale as covariate [173]. This was with the aim to compare the effect of *Pre* on *Post* measurements for the different Interventions *(Launch, Frame, Shine,)*. Thus, we study the difference between the interventions in terms of the relationship between the *Pre* and *Post* scores. A Two-way ANOVA with *Intervention* and *Stage (Pre/Post)* as factors were not adequate for the present study design, as it would lead to pairwise comparisons that are not meaningful given the between-subjects design (such as *Pre Launch Post Shine*). Dugard and Todman suggest that such analyses should be avoided [173]. We chose the ANCOVA approach as it was deemed the most suitable for pre/post designs by Dugard and Todman [173]. Dugard and Todman [173] showed how this approach offers increased validity over a repeated-measures ANOVA solution. This approach, however, results in the pre and post-scores being subject to two test. Thus, a Bonferroni correction of $\alpha = .025$ was used. All p-values reported in this paper are Bonferroni-adjusted. All details of the analysis can be accessed in the supplementary material.

For qualitative analysis, all audio recordings were transcribed verbatim and imported into Atlas.ti software. Initially, two authors coded eight interviews using open coding and established a coding tree through iterative discussion. The remaining transcripts were then individually coded by one author using the established tree. A final discussion session between two authors identified emerging themes through thematic analysis [83]. Additionally, one author re-experienced each participant's recording to deepen understanding and help with theme construction.

F.4.2 Participants

We recruited participants through our extended social network and snowball sampling, resulting in a diverse group of fifteen nationalities. A total of $n = 60$ participants evaluated MoodShaper quantitatively, and $n = 62$ participants provided qualitative feedback (14 females, 46 males, 2 non-binary; $M = 28$ years, $min : 20$ years, $max : 44$ years; see Section F.8 for details). To elaborate: initially, $n = 68$ participants were recruited, but six were excluded due to technical difficulties early in the study, and two experienced technical challenges towards the end of the VR experience, preventing them from completing post-test questionnaires, but they could still offer valuable qualitative insights. Participation was voluntary and unpaid, and participants self-assessed mental

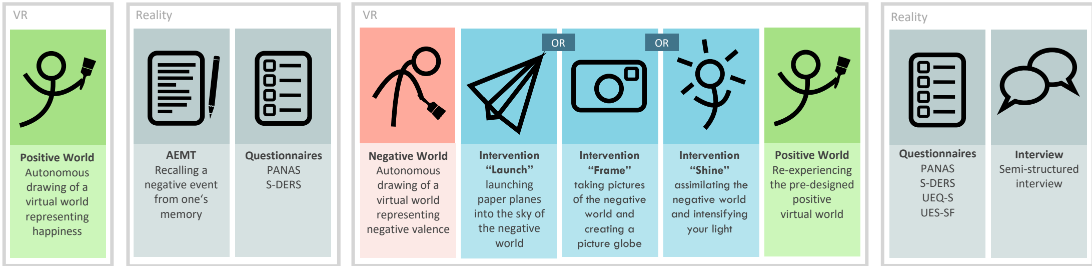

Figure F.4: Schematic representation of the MoodShaper procedure. Participants autonomously create a virtual world representing positive emotions. Then, they are induced with negative emotions and answer some questionnaires in reality. Then, they design a virtual world representing negative emotions, followed by experiencing one of three interventions (based on their condition) that allow them to manipulate their negative world. Afterwards, their self-created positive world reappears to go full circle. Post-intervention questionnaires and a semi-structured interview form the end.

stability. While our intended user group includes those struggling with mental health, we restricted participation for testing this prototype as a precaution due to our ethical responsibility. About half of the participants were regular VR users (34), while the rest used it infrequently (28). See Section F.8 for details.

F.4.3 Procedure

Google Forms guided participants through the study in our hybrid setting, with one researcher available for technical support if needed. For in-laboratory participation, a researcher prepared the technical, without further involvement ensuring consistency. After providing informed consent, participants watched a tutorial on VR controls for painting and world creation, and were briefed on the working of the indicator guiding through the interventions.

See Figure F.4 for an overview of the procedure. Participants entered VR to create a world representing happiness, serving both as an exploration phase to get used to the controls and a way to end positively after the intervention, as suggested by prior research [612]. This step also serves as an additional safety measure considering MoodShaper's status as a prototype; in real-world scenarios, MoodShaper would adapt to personal needs, allowing participants to immerse themselves in previously created positive worlds (e.g. if participants strive to only experience the ER interventions when feeling down) or create new ones to match their current emotional state (e.g. if participants want to use this step to mentally prepare for the ER task to come). Creating a positive world took on average 13 : 05 minutes. Participants then returned to reality, where a negative affective state was induced using the autobiographical emotional memory task (AEMT)[262], a widely used validated method in HCI [609, 611]. This mood-congruent procedure prompts participants to recall and write about recent situations, thereby increasing the likelihood of re-experiencing strong emotions [38, 370]. Participants followed the AEMT guidelines by describing a situation where they felt strong negative emotions. Then, participants answered the PANAS [619] (partly as a manipulation check of the AEMT and to allow for pre-post measurement) and S-DERS [314] questionnaires. They then returned to VR to create a world reflecting the emotions expressed in the AEMT. Subsequently; creating the negative world took 10 : 12 minutes on average. They performed their randomly assigned intervention (Launch Paper Planes, Frame a Picture Globe, or Shine Your Light). Participants spend about 4 : 08 minutes on average with the interventions. Upon completion, they were automatically returned to their previously created positive world and could end the study whenever they chose, staying there for 1 : 34 minutes on average. Back in reality, participants answered PANAS, S-DERS, UEQ-S, and UES-SF. Participants completed the AEMT and questionnaires in reality so that interventions and study setup remain separate, so simulate the experience of using MoodShaper as a consumer product. Remote participants saved and transferred their recordings and VR creations to the experimenter. Following completion, the experimenter conducted semi-structured interviews, averaging 18 : 22 minutes. In total, the study took an average of 1 : 25 : 36 hours (1 : 12 : 49 for laboratory study, 1 : 38 : 51 for remote study).

On a side note, determined through design choices and preliminary testing, we balanced repetitive movements and physical engagement, both known to enhance cognitive engagement [612], alongside the gradual disappearance of drawings, to ensure visual change without compromising efficacy. Effectively, the intervention phase was intentionally shorter than VR world creation. Post-test interviews confirmed that this balance provided adequate time for ER without being burdensome.

F.5 Findings

This section presents quantitative results from the questionnaires as well as qualitative insights from the interviews.

Table F.1: Mean values and standard deviations for PANAS and S-DERS subscales across the three conditions along with t-test statistics. The four S-DERS subscales measure different problems with ER. Thus, a lower score is 'better' for all S-DERS subscales. For PANAS Positive Affect a higher score is 'better' while for PANAS Negative Affect a lower score is more desirable. Statistically significant results are marked with asterisks *.

	PANAS				**S-DERS**									
	NA		**PA**		**Nonaccept.**		**Modulate**		**Awareness**		**Clarity**		**Total**	
Stage	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*
M	23.17	14.38	22.73	26.05	11.60	8.45	13.67	10.78	12.27	12.33	3.42	3.10	40.95	34.67
SD	8.943	4.267	7.390	7.139	4.917	2.740	5.313	3.309	3.204	3.977	1.769	1.734	11.017	7.469
t-test	$t = -3.284$		$t = 7.816$		$t = 5.796$		$t = 5.548$		$t = -0.151$		$t = 1.565$		$t = 4.8515$	
$df = 59$	$p = .002*$		$p < .001*$		$p < .001*$		$p < .001*$		$p = .881$		$p = .123$		$p < .001*$	

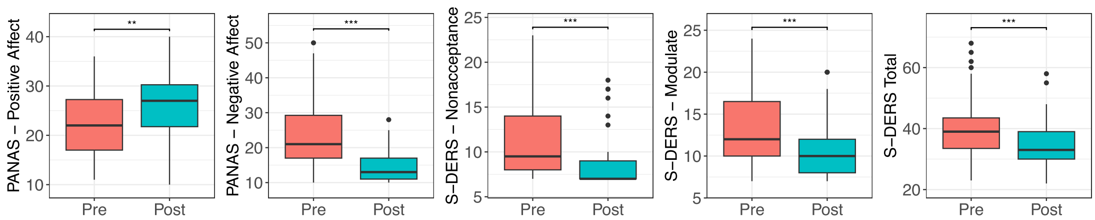

Figure F.5: Box plots showing the differences in *Pre* and *Post* measurements for the subscales with significant t-tests. A lower score is 'better' for all subscales apart from PANAS Positive Affect for which higher scores are 'better'.

F.5.1 Quantitative Findings

On a general note, due to the hybrid study design, t-tests were conducted to test for significant differences between study stages (*Pre* and *Post*). The results showed that there are no significant differences between the remote and lab participants for S-DERS ($p = .990$), PANAS Positive Affect ($p = .132$) and PANAS Negative Affect ($p = .362$). The participants were thus not grouped for further analyses.

Paired t-tests were conducted on *Pre* and *Post* measurements for the three interventions of all the subscales of PANAS and S-DERS. The differences were significant for all subscales except the *S-DERS* subscales *Awareness* ($p = .881$) and *Clarity* ($p = .123$) (see table Table F.1 and box plots in Figure F.5. ANCOVAs were conducted to compare the relationships between *Pre* and *Post* measurements for the different Interventions. This was performed by measuring the effect of the intervention type on each of the subscale *Post scores, controlling for the Pre score.* The ANCOVA was only significant for *Clarity* ($F_{2,57} = 3.278$, $p = .045$ $\eta^2 = 0.103$). Post-hoc testing with Tukey HSD

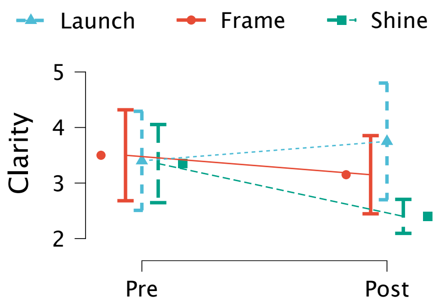

Figure F.6: Line plot showing the differences in *Pre* and *Post* measurements including standard error bars for the *Clarity* subscale across the three Interventions. The subscale measures limited clarity about one's current emotions and thus lower scores are 'better'. The *Clarity subscale was the only subscale for which the ANCOVA was significant. Shine scored significantly lower than Launch.*

showed that there was a difference between conditions *Shine* and *Launch*, at $p = .01$. as can be observed in Figure F.6 (see supplementary materials for all ANCOVAs). Consequently, we gathered no evidence of differences between the three Interventions with the exception of *Clarity* where *Launch* outperformed *Shine*.

UEQ-S scores for all the Interventions suggest that there were no notable user experience issues. *Launch* was rated with $UEQ\text{-}S_{Launch} = 1.069$, *Shine* with $UEQ\text{-}S_{Shine} = 0.963$, and *Frame* $UEQ\text{-}S_{Frame} = 0.706$. While the former is above average, the latter two are slightly below. All these scores are within a 'typical' range [502]. For both UEQ-S and UES a One-way ANOVA was conducted to investigate if there should be any differences in scores between the conditions. However, no differences in scores could be found depending on the condition, for UES ($F_{2,57} = 0.0406$, $p = .960$) and for UEQ-S ($F_{2,57} = 0.718$, $p = .492$).

F.5.2 Qualitative Findings

Based on our qualitative inquiry, five themes were construed from the data: *Complexity of Emotional Experiences*, *Regaining Control*, *Understanding the Process*, *Transcending to Reality* and *Potential & Risks*. Our findings are described below and illustrated with excerpts from the interviews. Example screenshots from participants' sketches can be found in Figure F.7.

Complexity of Emotional Experiences

The first theme focuses on the complex interplay between depicting negative emotions and their experiential emotional effects. Initially, participants faced greater challenges when attempting to visualise negative emotions compared to positive emotions, resulting in more abstract and complex representations. Hence, their negative worlds often reveal a mix of negative emotions, mainly encompassing anger, sadness, frustration, distress, and stress. In this context, participants reported that especially MoodShaper's simplified tool palette facilitated effective representation and reflection, despite or because of being in stark contrast to the complexity of emotions they aimed to convey. One participant explained:

> But this space reduces you to a kind of childlike capability in a way that feels like a safe way to engage with your emotional state. (...) The simplicity of the lines and the drawings lined up very nicely with how emotions are incredibly complex and to try and get very specific with them is usually either going to cost you a lot in therapy or not going to address the problem as a whole. That childlike clumsiness, I think, is the word that I would use. You have these very blunt tools that let you just mess around with colour and that there's no opportunity really to get very specific is really powerful. (P18)

The process of visualising and being immersed in complex negative emotions induced strong emotional responses among participants. Despite their abstract nature, negative emotions became corporeal and tangible through visual representation, exerting power over the participants. Participants frequently visualised feelings of helplessness and loss of control by enclosing themselves within their drawings, often crafting cages or caves around themselves or positioning themselves above an abyss to evoke sensations of danger and fear, as P61 described: *"I was thinking about a stressful situation and I, in fact, had made that situation even more stressful by creating this duct tape cocoon around myself"* (P61). This self-induced encapsulation triggered physical reactions in some participants, leading to reported unease, tingling sensations, and heightened heart rates.

Regaining Control

Our second theme revolves around the significance of regaining a sense of control through the MoodShaper interventions in order to feel empowered to break free from the negative emotional state. Thus, the majority of participants emphasised physical engagement which helped them to also get mental control over their emotions. Despite the consensus on this theme, opinions on which intervention was the most effective varied. For

(a) Positive World: P1 individualised the pre-defined virtual environment to create a cozy atmosphere where they feel happy. They added a vase with flowers, a picture on the TV, cake on the table, fire in the fireplace, and decorations on the shelf.

(b) Negative World: P65 used a dark black brush and the animated fire brush to draw a cage around themselves to symbolise the loss of power and hopelessness (for visualising purposes an outside view is presented here).

(c) Negative World: P30 drew their anger and frustration about an authoritative person denying them sushi. They chose a dirty industrial landscape as backdrop.

(d) Re-Experiencing Positive World: P31 found a place for the picture globe next to the bench and drew around it using colourful sparkles. This setup should symbolise the benefit of reflecting on negative emotions when being in a relaxed and positive state of mind.

Figure F.7: Sample screenshots from participants' sketches.

instance, some participants perceived throwing *Launch* as a highly active and empowering action (e.g. 48), while others found it *"too soft"* (P11, P19, P30) to address their negative emotions in a meaningful way. On the other hand, the *Frame* intervention made participants feel in control by containing negative emotions in a secluded space, *"visually shrinking their negative emotions into a smaller world"* (P34) as participant P34 put it, which allowed participants to perceive themselves as more physically and psychologically powerful, as *"oneself feels way bigger"* (P34). However, the act of taking pictures in this intervention was considered less physically active. In contrast, the *Shine* intervention provided a strong sense of control for participants, as it felt like a proactive approach to confronting and managing negative emotions, as it felt like *"actively tackling negative emotions and doing something with them"* (P55). The theme of re-gaining control is nicely illustrated by the following quote:

> There's obviously a very deep link behind interaction with physical things (...), like movements and the way that you kind of feel about them. (...) So doing something active, doing like movement in that way is helpful for dealing with emotions like that. (P8)

Understanding the Process

The third theme encompasses comprehensive insights into the impact of MoodShaper's composition on ER. Participants reported that initially, they encountered some confusion regarding the indicators and controls of each intervention, as well as the unexpected disappearance of their drawings. However, as they engaged more with the interventions, they realised that the dissolution of their drawings served to emphasise the ER aspect of the interventions, marking it as a release from negative emotions. In that regard, participants stressed the importance of the temporal aspect for successfully regulating emotions. Time was considered a crucial element of the transition phase, supporting them to shift from a state of being overwhelmed by negative emotions to a more reflective and composed mindset. One participant describes the transition phase as follows:

> Throwing these things several times was already better than only throwing once. Because it kind of graduates the emotion level piece by piece. If I just throw one thing now, then it could be that it's still stuck in my mind, and so it [the negative emotion] can gradually be reduced piece by piece, like, from the intensity maybe of my feelings. (P11)

Further, participants liked that MoodShaper facilitated the possibility of taking a step back and nudged them to change one's perspective. Participants reported that rotating 360° to see the drawing from different angles, and the interventions themselves, helped to focus on smaller aspects of the drawing. Thereby, *Launch* encouraged participants to hit certain parts of the drawing, and *Shine* made them shift focus on the intervention itself, as *"the glow was already something positive"* (P48), and how *"it somehow dissolves a bit the dark, somewhat dangerous environment"* (P48). *Frame* was considered to trigger the highest level of detachment from negative emotions, attributed to the presence of a camera. Participants described that they *"kind of stepped away from the canvas" (P28)*, taking on the role of an observer. Furthermore, it was surprising that participants transcended the interventions' intended designs, particularly when using *Frame*. Participants often mimicked interaction concepts central to *Launch*, i.e. closure by burying or concealing the globe in the positive world, *"to forget that they exist" (P21)*, and to *Shine*, embracing negative emotions by transforming the globe into something positive, drawing sparkles around it (i.e. see Figure F.7 d).

Lastly, participants appreciated the clear conclusion of the intervention phase, marked by the reappearance of the positive world. The positive world was considered a reward, which made *"positive memories flood in"* (P7), felt like a *"safe space"* (P57), a *"home"*

(P25) and *"like you were seeing an old friend"* (P42). It marked an endpoint and provided closure and satisfaction within the emotional regulation process, as one participant noted:

> For me in my head, I have dealt with the negative world now, it's now closed, and now I'm back, where I feel comfortable, in the safe space. Yes, that was a good conclusion, after you have to deal with the negative world, to come back to the positive one, it felt good. (P57)

Transcending to Reality

Our fourth theme, *Transcending to Reality*, deals with learnings from MoodShaper that are applicable to real life. Participants emphasised that their experience with MoodShaper felt like an activation of resources that would make them more resilient when managing emotions in real life. Further, they commented on being better equipped to accept negative emotions, i.e. not being embarrassed about feeling fear (P8), that it is normal to feel negative emotions (P25), and as a reminder that one is not "invalidating [negative] feelings when you don't let them consume you (...), it's not like you have to let them ruin your whole day" (P31). Effectively, some participants also proposed to create a real artefact as a reminder, *"so that I could engage with it outside of VR"* (P29).

Some participants were also inspired to reflect on their personalities. For instance, P19 pondered about what it reveals about their character that they enjoyed the most active and "aggressive" (P19) intervention the most. As such, participants described MoodShaper as creating self-insights and self-growth:

> I need a little bit more 'boom'. A little bit more of destruction, when I am angry. What does that say about me, now, as a person? (P19)

Ambivalent Experiences

The fifth theme focuses on opportunities and risks when using MoodShaper. Participants considered MoodShaper to be an *"exciting, playful"* (P3) and *"meaningful"* (P13) VR application. They stated that VR allows for lightness when approaching a "heavy" topic such as ER which is difficult to achieve in reality, and many mentioned that they were surprised by how well the interventions of MoodShaper actually work. One participant emphasised that MoodShaper *"helped heal an emotional wound I had for a year"* (P7). Participants viewed MoodShaper as an appealing self-care tool, valuing its enjoyment and high privacy factors. They also envisioned its potential in therapeutic settings. One participant reflected:

> I think it might be a cool tool for a therapeutic application, where you have more room to express yourself, and you also feel completely private in this environment. I think this is also what I would use it for, to be reflective. That's what it's meant to do, to be reflective of your own emotions. (P28)

However, participants reported that the effectiveness of the interventions to support reflection varied across situations and designated emotions. For instance, P19 emphasised that *Launch* would work for sadness, while not for anger or frustration as it is *"too soft"*, while P8 found *Frame* to work best for sadness as well as for certain situations that one cannot face at that moment. Additionally, interpretations of the interventions varied a lot across participants. For instance, some participants viewed *Launch* as a way to externalise and release negative emotions, as intended, while others interpreted it as an active act of destruction aimed at eradicating the negative world. Despite the different interpretations, both were regarded as successful ER strategies. Similarly, *Shine* generated ambiguous reactions. One prevalent interpretation involved absorbing, internalising and accepting negative emotions, as designed, but some interpreted the burst of light as a sign of destroying negative emotions.

Moreover, participants reported being deeply immersed in MoodShaper, losing track of time and surroundings, particularly in negative worlds. This deep immersion led to a heightened awareness and emotional connection to positive elements afterwards, realising more details and they *"felt much more connected"* (P37) to the positive drawing than before. However, others reflected on the risks of being that deeply immersed, and of *"lingering emotions"* (P28) after the intervention phase. These risks are exacerbated by the experience of software bugs and glitches. One participant, who is a VR developer and very experienced with the concept of presence, shared their insights about the speed and intensity with which negative emotions were intensified when the intervention (i.e. *Launch*) surprisingly did not work:

> When I was unable to escape this negative space that you've created because of the software bug, the gravity and speed with which frustration occurred were intense. I find that very interesting that something like being stripped of your agency at the very moment that you need it most is something that VR could afford you. (...) It is a feeling of helplessness that is really extraordinary. And because I've worked in VR, I've felt it before in a much less intense way. But here, you forget that you are in a virtual space. And

> so when your ability to engage with that space suddenly disappears, you're utterly helpless for a moment until you remember to take the headset off. (P61)

F.6 Discussion

In this work, we endeavoured to understand how VR can provide technologically-mediated support for managing everyday negative emotions. Users employed a diverse set of tools to create visual representations of both positive and negative emotions in VR. They then engaged in one of three carefully designed interventions aimed at regulating these negative emotions through manipulation of the drawing representing negative emotions. As the vision of this work is to extend the design space of ER support in VR, we do not aim to replace established practices and interventions. Instead, the goal of this work is to extend the "room for manoeuvre" when engaging with (challenging) emotions. Emotional experiences and how people deal with them are complex [455], thus we need to expand the tool palette which people can use for ER support. Hence, we hope that our work - may it be by the design and the usage of our prototype MoodShaper or through our design recommendations applicable to other VR systems for ER support through VR - inspires future systems that can be used by people in their everyday life as part of their mental well-being routine. In the long run, we envision that our insights might also lead to systems that can be useful in clinical contexts to support participants in their mental health journey with the help and guidance of mental health experts.

In this section, we present our key findings, discuss MoodShaper's relevance to and expansion of existing research and situate them within the broader context of HCI research. Further, we outline implications for the HCI community and beyond when designing VR experiences for learning and practising ER strategies. We also reflect on limitations and opportunities for future research.

F.6.1 Ludic Engagement for Serious Contexts

This section is partly based on and inspired by the themes *Complexity of Emotions*, *Regaining Control* and *Ambivalent Experiences*. We will discuss how playful design, coupled with clear objectives, can boost user confidence and control when experiencing negative emotions. This can also promote mindfulness, potentially contributing to healing and self-growth, in line with previous work [265, 387, 513, 524]. Our quantitative results indicate that MoodShaper offers an engaging experience (UES-S) that enhances positive affect (PANAS-PA). This is in line with our qualitative findings, where participants expressed childlike joy while using the tool palette in VR, describing a sense of lightness not achievable in reality. While the tool palette can be used to create artistic paintings [1], our sample described having limited artistic expertise, describing a "childlike clumsiness" (P61) when visualising complex emotions. Still, most lost track of time, disregarding external factors (e.g. the experimenter's presence in the laboratory), and experienced strong emotions within their virtual negative worlds—indicative of presence [462]. Thus, MoodShaper aligns with research suggesting that VR can evoke visceral emotional responses akin to reality (e.g. [240, 331, 467]) through immersive environments [330]. Notably, many VR applications for mental health emphasise photorealistic landscapes (for an overview we refer to Wagener et al [606]). However, our qualitative findings are indicative that simple yet playful VR drawing tools could effectively foster presence - when combined with clear intent communication and a high degree of personalisation features.

Further, these findings also underscore that a ludic approach appears promising when addressing serious, complex and emotionally challenging topics such as negative emotions. MoodShaper's strength lies in its combination of playfulness and clear intent, making it particularly effective for addressing serious and emotionally challenging topics like negative emotions. Importantly, MoodShaper was not designed as a serious game [14, 90] with the purpose of teaching serious content in a gamified manner (compare F.3). Instead, the design rationale was to support the engagement with and the processing of challenging emotions in a reflective manner. Thus, we recommend:

RECOMMENDATION 1—Integrate ludic elements with a strong and meaningful purpose when addressing serious and emotionally challenging topics.

F.6.2 Reflection in VR and Beyond

In this section, we will discuss insights of the themes *Understanding the Process* and *Transcending to Reality*, highlighting which elements of MoodShaper's process were perceived as especially helpful for ER and how a clear process can support reflective insights that go beyond VR and facilitate internalising of ER strategies that can be applicable to future real-life situations. Our findings indicate that MoodShaper evokes reflection. First, participants reflected on the meaning behind and effects of the interventions while performing them. Second, they also explored their depicted emotionally charged situations, insights about their character, and behavioural strategies for ER in relation to these situations and beyond. They also reflected on their fundamental views

[1] for some examples we refer to TiltBrush Artists in Residence, https://www.tiltbrush.com/air/

about negative emotions and how to manage them in real-life contexts. These findings are in line with the definition of reflection by Schön et al. [511], defining it as understanding, thinking about potential courses of action, and one's role within these [511]. On a more granular level, and used by about 70% of HCI papers that explicitly define reflection [48], we encountered reflection-in-action, occurring during the action (i.e. while engaging with the interventions in MoodShaper), and reflection-on-action, using memories to reconstruct an experience, re-organising them to give meaning and draw lessons for the future (i.e. during drawing phases and in the interview) [511]. Participants attributed the reason for reflection to remembering the specific emotional situation, and to the design choices of the interventions: establishing emotional distance (e.g. using a camera to distance oneself from the emotions [300]), altering spatial perspectives to also change mental and empathic perspectives [185] (e.g. having to interact with the representations of negative emotions from eight different perspectives), and mirroring the effort involved in ER processes through the temporal aspect [612]. Thus, as reflection can be a challenging activity and often needs to be encouraged [539], our design approach (see Section F.3), seems effective in providing this encouragement. Importantly, our qualitative data suggested that MoodShaper actively discouraged rumination by encouraging reflection and providing a clear, positive endpoint to the ER process [213, 570].

Recommendation 2—Integrate a transition phase and a clear ending to facilitate and conclude the reflection process effectively.

F.6.3 Transformative Experience

Here, drawing upon findings presented in *Transcending to Reality*, we will outline how MoodShaper had created lasting impact on participants, highlighting how VR designers could strengthen and prolong the impact of VR-based interventions to generate lasting change. While not applicable to all participants, our study highlights the capacity of MoodShaper to evoke various levels of reflection [195]. Fleck and Fitzpatrick [195] outline a spectrum encompassing five consecutive reflection levels, ranging from level 0 (Description) to level 4 (Critical Reflection) [195]. Qualitative data suggests that some participants reached level 1 (Reflective Description), reinforcing their existing perspectives on negative emotions and their regulation strategies. Others progressed to level 2 (Dialogic Reflection), discovering new approaches to managing negative emotions. Moreover, the data indicates instances of level 3 (Transformative Reflection), where participants reported fundamental shifts in their formerly negative outlook on "negative emotions", signaling successful cognitive restructuring [308].

Participants further reported discovering more effective ways to handle emotionally challenging situations in the future through using MoodShaper. Consequently, MoodShaper served as a "mastery experience" for some participants. This aligns with principles of Agentic Positive Psychology [36], which describes that by reflecting on a personal success story the confidence in one's ability to succeed can get enhanced [37]. Such mastery experiences can drive positive behaviour change and lead to a sense of self-growth and self-efficacy [37].

To remind themselves of the 'mastery experience', their reflective insights and the feeling of having grown, some participants expressed a desire to carry a physical object back into the real world. This desire for tangibility reminiscent of the virtual experience in MoodShaper likely stems from the physical qualities assigned to negative emotions, such as tangibility and corporeality. Ascribing a physical or almost haptic quality to experiencing emotions in VR is in line with previous work [609]. It may also be influenced by the transition of the picture globe from the negative world to the virtual positive one in the application. This finding extends previous research where participants wanted to create a virtual catalogue of their VR experiences [609]. As such, we recommend:

Recommendation 3—Reinforce users' reflective insights by transforming reminders and emotional experiences made in VR into tangible objects that can be transferred to reality.

F.6.4 Opportunities and Risks

In this section, we draw upon findings of the themes *Understanding the Process* and *Ambivalent Experiences*, emphasising the (potentially negative) effects when feeling intense emotions. We will discuss specific safety mechanism, design choices and necessary future research that could mitigate risks and strengthen opportunities of VR applications aiming to provide ER support. During the study, participants raised critical concerns and emphasised the need to discuss opportunities and risks of using MoodShaper to an equal degree. Our findings in that regard will be critically reflected on in the following. One noteworthy finding in MoodShaper was the swift and deep sense of presence reported by many participants. As an example, an experienced VR developer shared that when they encountered a software bug, it made them momentarily panic and forget they could remove the VR glasses. This highlights both the potential and risks of potent VR applications addressing negative emotions, reinforcing expectations by therapists [606]. It also emphasises the importance of involving all stakeholders - VR developers, interaction designers, therapists and endusers - throughout the whole study process to uncover and mitigate these risks, as well as the need for longitudinal studies with therapist guidance to assess long-term effects.

Despite MoodShaper being based on therapists' expertise [612], therapeutic practices (i.e. art therapy [343]), and psychological constructs (i.e. cognitive restructuring [308]), some participants still interpreted the metaphors in the interventions differently. Particularly, *Shine*, originally designed to allow for embracing negative emotions, was sometimes misconstrued as an attack, alas only from participants who had solely watched the demonstrational video. This example illustrates the challenge HCI researchers face when balancing the creation of self-care therapeutic interventions for home use, as desired by participants, while minimising the risk of inadvertently causing distress or harm to users.

Managing Risks

To address these challenges, we stress the importance of incorporating safety measures in all VR applications aiming to provide support when managing challenging emotions. Based on prior research (i.e. [612]) and our own findings, applications should provide clear visual endings that feel like closure to prevent rumination. Additionally, warning and risk notifications should be added at the beginning of the intervention to raise awareness, as also previously suggested by therapists [606]. Recognising that studies are required to properly inform participants of the potential risks of participating in a study and to obtain informed consent, this is an implication especially relevant for practice [591]. Furthermore, when made available on platforms like Steam, applications such as MoodShaper can easily be misclassified as wellness applications. Here, policymakers should intervene to establish regulations that mitigate the risk of users encountering (un-)intended harmful design when downloading such applications. This is in line with previous work that discusses the tensions and potential risks (both from a user as well as from a legal perspective) of classifying health and well-being apps as either medical or health apps [339]. Moreover, applications such as MoodShaper should be adapted to specific needs of different age and user groups, being particularly considerate when designing for vulnerable user groups. To elaborate, prior works have identified specific needs of children [578], teenagers [63, 194, 293] and older adults [373] when dealing with emotions. Here, a combination of participatory design approaches [293, 578] and longitudinal studies is recommended to build an understanding of age-group-specific needs and requirements. Without further research, for now, MoodShaper should be restricted to adults only to mitigate risks such as re-introducing traumata. Future work should also investigate needs of more diverse users such as users who are not affine to technology, neurodivergent users, as well as those with various mental health issues.

For instance, people with ADHD or people experiencing depression will probably need different support. However, to date, little research has been conducted in regard to using VR in both fields [28]. In the long run, we envision that MoodShaper and the insights gathered in this study might lead to systems that can be useful in clinical contexts to support participants in their mental health journey. This process entails further risks, as it includes vulnerable user groups. Consequently, such a system would need to undergo prior meticulous testing through longitudinal studies in order to get clinical approval. Further, it would have to be appropriately integrated in and adapted to different therapeutic approaches. Along similar lines, safety measures, such as additional support and guidance outside of the therapy sessions might need to be provided by mental health experts. Based on prior research [540, 606], we hypothesise that in clinical settings a higher level of scaffolding might be beneficial. However, this might limit users' autonomy. We envision a step-by-step guidance paired with psycho-educational elements informing about the underlying psychological principles of each intervention, either by visual means or through voice-based guidance as formerly explored in regard to reflecting on personal challenges [611]. Lastly, we call upon HCI researchers to recognise their responsibility in reporting negative incidents, albeit rare, in their publications. By upholding these ethical standards, they can serve as valuable drivers for improving the design of VR applications aimed at preventing negative emotions from escalating uncontrollably. Thus, we recommend:

Recommendation 4—**Incorporate evident risk notices and integrate fail-safe mechanisms and appropriate support mechanisms to avert harmful design.**

F.6.5 Limitations & Future Work

In this section, we discuss the limitations of MoodShaper. We adopted an exploratory design in line with similar research ([225, 440, 516, 609, 611]), and fitting to our research objective to design experiential ER strategies in VR that support untrained individuals in regulating and reflecting on common everyday negative emotions, offering in-situ and offline support. While our approach effectively informs the design of future similar systems, we recognise that an alternative study, comparing it to other (possibly non-VR) systems would need to be conducted to further assess the system's effectiveness in ER. We refrained from comparing our work with past research systems using autonomous self-design of virtual environments as these works do not offer ER interventions (e.g. [516, 609, 611]), or lack the means for autonomous visual expression (compare [373]) or require technical skills not feasible for our target group (e.g. [225]).

Given the novelty of the experience of MoodShaper, our primary aim was to understand its impact on users' ER processes. This way, we can effectively inform the design of future VR systems for ER. Nevertheless, based on the exploratory evidence generated in this study concerning the interplay between the key constructs (e.g. relationship between autonomous expression and efficiency of three ER interventions), future studies on similar tools could compare our approach to other established ER methods.

We opted for a hybrid study approach to target VR users interested in engaging with negative emotions in their daily lives while being mindful of data-gathering risks. For a comprehensive overview of the benefits and limitations of this approach, please refer to Ratcliffe et al. [448]. In this study, we observed no significant differences between remote participants and those in the laboratory, but we acknowledge that we could not fully control all variables that may have influenced our data.

MoodShaper is intended for individuals interested in developing and practising effective ER strategies and who seek relief from negative emotions, regardless of their mental health. In this study, we restricted participation to self-indicated mentally healthy and well-balanced people out of ethical concerns when testing the prototype. Due to the broad profile of our target group, we opted for self-assessment instead of validated mental health assessments such as GAD-7 or PHQ-8, in line with other research in this area (e.g. [609, 611]). Furthermore, the procedure of MoodShaper was adapted for study purposes as well. Our design, especially the autonomous creation of the positive world and re-experiencing it in the end, were based on recommendations of therapists to always end such interventions on a positive note [612]. However, in real-life use cases, especially when used over a longer time, some participants might not want to spend the time on creating or being in a positive world, rather focusing on the intervention itself, while others might particularly enjoy the mental preparation that creating a safe space can offer. We envision MoodShaper to cater for these individual preferences. However, changes in the study design and how they might affect the overall experience of users should be tested in advance by future research. Based on the exploratory evidence generated in this study, future work could further explore MoodShaper or similar ER approaches using VR with participants struggling with mental health issues. However, we emphasise the risks associated with engaging this vulnerable user group and strongly recommend careful consideration of the study design and the incorporation of therapeutic safety measures.

F.7 Conclusion

To provide a novel way for managing negative emotions in VR, we created MoodShaper – a VR application allowing users to visualise emotions by autonomously creating a virtual environment and providing three interventions (*Launch, Frame, Shine*) on how to manipulate these visual representations with the aim to explore ER strategies. Quantitative and qualitative findings of a hybrid study with 60 participants showed that MoodShaper significantly decreased problems with ER and negative effects while increasing positive affect and engagement. Users felt empowered through the interventions and reflected on personal insights beyond the application itself. With our work, we emphasise the importance of playful design to explore complex negative emotions and discuss opportunities and risks when engaging with negative emotions using VR. In sum, there seems to be promise in building VR experiences for managing emotions in which users can freely express themselves while also receiving interventions that provide necessary distance, perspective-taking and reflection opportunities scaffolding the ER process. We hope our work and design recommendations inspire designers and researchers to further explore this promising research field.

F.8 Appendices

Table F.2: Overview of our participant sample. Participant-ID's have been reassigned for anonymity and clarity. Participants marked with asterisks (*) have experienced technical difficulty towards the end of the study and were only part of qualitative feedback. The (+) indicates that more VR activities were given.

P	Intervention	Setting	VR-Device	Age	Gender	Nationality	VR-Usage	VR-Activities
1	Launch	Remote	HTC Vive Pro 2	44	Male	German	Daily	Games, Social
2	Launch	Remote	Valve Index	38	Male	Canadian	Weekly	Games, Social
3	Launch	Remote	Valve Index	31	Male	Danish	Weekly	Games, Social, Fun
4	Launch	Remote	Valve Index	25	Male	German	Monthly	Games, Sport
5	Launch	Lab	Meta Quest 2	27	Male	German	Sporadical	Studies, Games
6	Launch	Remote	HTC Vive Pro	23	Male	USA	Weekly	Studies, Social, Sport, Health+
7	Launch	Remote	Valve Index	31	Male	USA	Weekly	Games, Social, Fun
8	Launch	Remote	Oculus Rift CV1	23	Male	German	Monthly	Games, Sport, Research
9	Launch	Remote	Meta Quest 2	31	Male	Malaysian	Yearly	Studies, Games
10	Launch	Remote	Meta Quest 2	28	Male	German	Monthly	Studies, Games - Museum
11	Launch	Lab	Meta Quest 2	26	Female	German	Never	None
12	Launch	Lab	Meta Quest 2	30	Male	German	Weekly	Studies, Games, Research
13	Launch	Remote	Meta Quest 2	23	Male	Dutch	Weekly	Games, Social, Sport, Fun
14	Launch	Remote	Valve Index	32	Male	Canadian	Weekly	Games, Social, Sport, Fun
15	Launch	Lab	Meta Quest 2	31	Male	German	Yearly	Studies, Games, Development
16	Launch	Lab	Meta Quest 2	27	Male	German	Yearly	Studies, Games, Sport
17	Launch	Lab	Meta Quest 2	35	Female	Iranian	Sporadical	None
18	Launch	Lab	Meta Quest 2	31	Male	German	Sporadical	Games
19	Launch	Lab	Meta Quest 2	29	Female	German	Sporadical	Games
20	Launch	Lab	Meta Quest 2	26	Male	German	Sporadical	Studies, Games
21	Frame	Remote	Meta Quest 2	20	Male	Polish	Weekly	Games, Social
22	Frame	Remote	Meta Quest 2	37	Male	USA	Yearly	Games, Social, Fun
23	Frame	Remote	Oculus Quest pro	27	Male	British	Weekly	Games, Social, Sport
24	Frame	Lab	Meta Quest 2	26	Male	German	Sporadical	Games, Fun
25	Frame	Lab	Meta Quest 2	25	Female	Chinese	Monthly	Studies, Sport
26	Frame	Lab	Meta Quest 2	28	Female	German	Sporadical	Social
27	Frame	Lab	Meta Quest 2	27	Female	German	Monthly	Studies, Work
28	Frame	Lab	Meta Quest 2	28	Male	German	Sporadical	Studies, Social
29	Frame	Lab	Meta Quest 2	31	Male	German	Sporadical	Marketing
30	Frame	Lab	Meta Quest 2	32	Male	German	Yearly	Studies, Sport, Development
31	Frame	Lab	Meta Quest 2	28	Female	Greek	Yearly	Studies
32	Frame	Lab	Meta Quest 2	25	Male	German	Monthly	Games
33	Frame	Lab	Meta Quest 2	30	Male	German	Yearly	Studies, Development
34	Frame	Lab	Meta Quest 2	25	Male	German	Yearly	Studies, Games, Work
35	Frame	Remote	HTC Vive Pro Eye	28	Male	German	Daily	Work
36	Frame	Remote	Valve Index	27	Male	USA	Weekly	Games, Social, Fun
37	Frame	Remote	Meta Quest 2	30	Male	German	Yearly	Studies, Games, Fun
38	Frame	Lab	Meta Quest 2	29	Female	German	Yearly	Studies, Fun
39	Frame	Lab	Meta Quest 2	30	Male	German	Yearly	Studies, Games
40	Frame	Lab	Meta Quest 2	25	Female	German	Sporadical	Studies, Games
41	Shine	Remote	Valve Index	26	Male	French	Daily	Studies, Games, Social, Sport+
42	Shine	Remote	Valve Index	37	Male	British	Weekly	Games, Social, Sport, Fun
43	Shine	Remote	Oculus Quest 1	23	Male	Dutch	Monthly	Games, Social, Fun
44	Shine	Remote	Valve Index	21	Male	Swedish	Daily	Games, Social, Sport
45	Shine	Remote	Valve Index	28	Male	Dutch	Weekly	Games, Social, Sport, Fun
46	Shine	Lab	Meta Quest 2	27	Male	German	Monthly	Studies
47	Shine	Lab	Meta Quest 2	32	Male	Iranian	Sporadical	Studies
48	Shine	Remote	Meta Quest 2	32	Female	German	Yearly	Studies, Fun
49	Shine	Remote	Valve Index	27	Non-binary	Austrian	Daily	Games, Social, Development
50	Shine	Lab	Meta Quest 2	31	Female	German	Monthly	Studies, Development
51	Shine	Remote	Valve Index	27	Non-binary	Canadian	Weekly	Games, Social
52	Shine	Remote	Valve Index	27	Male	Puerto Rican*	Daily	Games, Social, Sport, Fun
53	Shine	Remote	Valve Index	26	Male	German	Daily	Games, Social, Sport, Fun
54	Shine	Remote	Valve Index	24	Male	Polish	Daily	Games, Social, Sport
55	Shine	Remote	Meta Quest 2	29	Male	Austrian	Weekly	Studies, Games, Social, Fun
56	Shine	Remote	Valve Index	20	Male	German	Monthly	Games, Social, Sport
57	Shine	Lab	Meta Quest 2	26	Male	German	Yearly	Studies, Sport, Development+
58	Shine	Lab	Meta Quest 2	30	Male	German	Sporadical	Health
59	Shine	Remote	Oculus Quest 1	24	Female	German	Monthly	Studies, Games, Fun
60	Shine	Lab	Meta Quest 2	31	Female	German	Never	None
61*	-	Remote	Meta Quest 2	39	Male	American	Daily	Studies, Games, Development
62*	-	Remote	Meta Quest 2	28	Female	German	Sporadical	Studies, Fun

Part V

DISCUSSION

Joy:
"You can't focus on what's going wrong. There's always a way to turn things around, to find the fun!"

Sadness:
"I know you don't want me to be here, but I'm here to help you feel better."

– from the Disney/Pixar movie *Inside Out*

3 Discussion

This dissertation describes an exploratory journey to understand how VR can be designed as a technology for self-care (SCT) for people who are untrained in self-care strategies and aim to improve their mental well-being. Through a comprehensive examination spanning multiple objectives, I address the societal shift towards autonomous mental health management, exploring the intricacies of designing VR environments that cater to the varied needs of people and to a range of emotions. Thus, the central research question (**Central RQ**) was: **How can VR applications be designed to facilitate self-care practices for everyday mental well-being?**. It was deconstructed into three distinct questions.

Part I identified research gaps identified from HCI literature and established essential terms and concepts for this dissertation. Part II systematically reviewed consumer VR applications through the lens of mental health professionals' expectations, identifying key design challenges. Part III and IV introduced interactive VR prototypes of self-care activities and empirically evaluated their effectiveness. Thereby, Part III focused on examining the design of the virtual space to facilitate introspection. It offered insights into how various sensory modalities - such as haptic, auditory, and visual - can be integrated into a self-care VR application to facilitate the process of self-awareness without distracting users from their self-care goal. Part IV explored novel strategies for incorporating scaffolding into VR-based SCTs to guide users more effectively through their self-care journeys. This part highlighted the potential of verbal and metaphoric visual scaffolding to enrich the self-care experience, deepen reflection and facilitate personal growth.

This section, Part V - *Discussion*, first reflects on how the publications contribute to answering all RQs. Afterwards, based on the findings of this dissertation, it will contribute design implications and a process model providing guidance when designing engaging and effective self-care applications. This chapter will then reflect on the limitations of this dissertation and point towards several promising suggestions for future research. The conclusion summarises the take-away messages of this thesis.

3.1 Discussion of the Research Questions

This section is dedicated to investigating how findings from the publications helped to answer the **Central RQ**: **How can VR applications be designed to facilitate self-care practices for everyday mental well-being?** This central RQ was divided into three distinct questions, exploring key design challenges (RQ1), the impact of various modalities employed within the virtual space on self-care (RQ2), and the design and impact of virtual scaffolding to guide users through their self-care journey (RQ3).

3.1.1 Revisiting the Central RQ

To reflect how findings answered the **Central RQ**: **How can VR applications be designed to facilitate self-care practices for everyday mental well-being?**, this section first discusses how VR-based self-care can or cannot overcome current barriers to self-care. Then, it reflects on the method of self-creating virtual environments, emphasising its strengths and challenges. Next, this chapter explores how VR-based self-care applications can impact everyday emotions and challenges, thus discerning different use cases. As this dissertation uses an open-ended approach, both in the study designs as well as in the self-care approaches tested, the last part compares the benefits and drawbacks of structured and open-ended approaches to testing.

Addressing Current Barriers to Self-Care

There are various barriers that currently impede the effectiveness and seamless integration of SCTs into daily life, such as environmental distractions, lack of adaptability, and task complexity [135, 164, 405]. This section will explore how our findings can address these barriers. Notably, I solely discuss barriers that can be related to VR; others that specifically address other SCTs, such as wearables or mobile applications, are not discussed here.

Environmental Distractions. One key barrier of self-care is being distracted from self-care practice by the ongoing demands of daily life [135]. Across all studies and prototypes evaluated, participants highlighted the benefits of VR in that regard. They reported being immersed, feeling present, forgetting the time due to being in flow, being able to withdraw from daily struggles, and having a space that is meaningful to them and which helps them to be alone with their thoughts and emotions and spend time with themselves. Thereby, it is not solely the aspect of isolation that makes VR a suitable SCT to overcome this barrier. It is also due to dynamic elements, immersive

360° environments, sound, haptic feedback, and emotionally engaging virtual spaces. These features significantly enhance user engagement, making VR a compelling self-care medium. Additionally, most participants expressed a desire to continue using the self-care prototypes. Overall, it was found that VR can facilitate perspective-taking and empathic understanding, as well as enhance creativity, competence, self-efficacy, self-knowledge and personal growth; how this was supported will be discussed in more detail throughout the whole chapter. In sum, I found that the immersive space of VR was able to effectively isolate users from real-world distractions, encouraging dedicated focused time to self-care practice.

In-Situ Support. There is a growing demand for SCTs to be compact, portable devices that offer on-the-go mental well-being support [496]. With the current hardware, VR cannot meet this need. VR systems are primarily stationary and not well-suited for public use due to their cumbersome hardware, short battery life, and demanding setup, limiting their utility for spontaneous, in-situ support. However, the strength of VR lies in creating a private space for users to engage with their emotions and thoughts, insulating them from the distractions of daily life. Therefore, it might not strive to meet this particular self-care barrier, rather complementing other SCTs such as wearables of mobile applications which can provide in-situ support. Yet, imagining a future where users could immerse themselves in VR during a brief break from work suggests that hardware development in regard to portability and setup speed could be a worthwhile endeavour.

Nonetheless, this dissertation could inspire the development of augmented reality (AR) applications that utilise similar self-care techniques such as self-creation and self-expression as presented in this thesis. In AR, virtual elements overlay the real world which is still partly visible to the user. In an ongoing project, I employed this concept by allowing users to control weather elements (sun, rain, snow, wind) through mid-air gestures, tailored to their mood states (happiness, anger, sadness). Preliminary findings indicate that the system is intuitive and engaging, providing immediate stress relief and on-the-go self-care support. However, integrating emotional self-expression into AR also presents certain challenges that must be thoughtfully considered. This includes potential physical risks such as obstructed visibility of the surroundings by AR elements, discomfort from being observed in public, and using it in unintended ways such as modifying the appearance of others, and so diverging from self-care purposes.

Limited Spectrum of Self-Care Activities. Cornet et al. [135] emphasised the ongoing need to broaden the spectrum of self-care activities, and posited that novel design solutions should be explored that focus on self-reflection, mastery and skill development. This dissertation addressed this barrier by focusing on a diverse range of self-care activities, including mindfulness, self-reflection, self-expression and emotion regulation. These were chosen as a combination of renowned approaches (i.e. mindfulness-based stress relaxation [601]), ones that are often found as by-products in VR research but lack emphasis when designing prototypes (i.e. self-reflection [304]) and under-researched ones (i.e. self-expression [290]). Focusing on these self-care activities also allowed to cover the range of emotional experiences and challenges of everyday life, addressing negative, neutral and positive emotions and experiences. The insights from this dissertation will help guide the development of future VR-based SCTs in research. Hopefully, it will also help broaden the offerings on the consumer market which is currently dominated by VR gaming applications [62], and, within the mental health and well-being domain, by guided meditation applications, as found in *A - AppSurvey*.

Inadequate Design. Another identified barrier is "poor" design of self-care applications that can reduce user engagement and effectiveness [135]. However, despite existing design recommendations for SCTs in general (e.g., [164, 551]), there is limited research that clearly delineates what constitutes "poor or good design" specifically for VR-based self-care technologies aimed at laypeople. To address this research gap, paper *A - AppSurvey* reviewed the design of consumer VR applications, guided by insights from mental health professionals. The resulting guidelines, such as customisable options, including physical and psycho-educational elements, and providing a safe space informed the design of subsequent VR prototypes and can inform future research as well. However, the implementation of these design recommendations is only partially explored in this thesis, presenting opportunities for further research. Notably, these guidelines are limited to a review conducted on the expectations of mental health professionals. We decided to focus on their expertise as a first step as they are trained and experienced in supporting individuals in pursuing self-care practice by teaching strategies for self-growth and overall mental well-being. Future work could additionally identify expectations by other stakeholders, such as VR designers.

Lack of Adaptability and Personalisation. In line with one of the key design challenges as identified in *A - AppSurvey*, a main challenge for SCTs is to provide adaptability and personalisation, meeting unique contexts and preferences of users [135, 164, 405].

To address this aspect, research suggests targeting personal values, individualised content, and personalised displays [164, 405]. In this dissertation, evaluated across three studies, I found that autonomously self-creating a virtual environment as a means to provide a high level of autonomy and customisation was effective in creating meaningful experiences. Specific strengths and drawbacks will be discussed in detail in Section 3.1.1 and Section 3.1.1.

Task Complexity and Lack of Engagement. As another barrier, the complexity of self-care activities was identified, which can result in a lack of engagement [135]. To address this, research suggests simplifying tasks and providing motivational elements to manage the complexity of self-care practice [135].

To reduce the perceived complexity of tasks, scaffolding proved effective in encouraging the sub-division of complex tasks (such as visualising multifaceted challenges or emotions) into smaller manageable parts. In *E - SelVReflect*, voice-based guidance motivated users to visualise a challenge as single steps. In *F - MoodShaper*, using the visual metaphoric interactions such as throwing paper planes promoted a focus on specific segments of the VR drawing. This design was intended to facilitate spatial perspective-taking and simplify the complexity of negative emotions. The interactions required users to engage with the drawing from different perspectives, thus promoting the viewing of a complex negative emotion as a mix of smaller manageable parts.

Further, this dissertation's prototypes incorporated motivational elements in various ways to ensure continuous engagement, in line with Woodward et al.'s recommendations [636]. These elements included beautiful virtual environments (*B - Haptics*), dynamic weather scenarios (*C - VeatherReflect*), voice-guided affirmations and encouragement (*E - SelVReflect*), playful metaphoric interactions (*F - MoodShaper*), and ludic approaches such as self-creation using a toolbox of animated brushes (*D - MoodWorlds*, *E - SelVReflect*, *F - MoodShaper*). While these elements were found to effectively engage users, generalising their impact is challenging due to high interpersonal variations and the exploratory nature of this work.

Personal Habits. Self-care activities may also clash with personal habits [135]. While no longitudinal studies were conducted to explore how self-care activities integrate into or collide with personal routines (for more information, see Section 3.4.1), based on comprehensive findings, we can still assess the impact of personal factors on the effectiveness of self-care activities.

For instance, effective VR-based self-care requires foundational health literacy, particularly for self-awareness-related tasks. Such tasks have the power to evoke strong emotions, as shown in papers *D - MoodWorlds*, *E - SelVReflect*, and *F - MoodShaper*. However, there were occasional instances in our studies where VR did not successfully transform negative emotions into positive outcomes, due to technical issues, unintended usage or individual factors. To counteract this, systems could implement a "distress button" that, when pressed, would suggest alternative non-technical self-care strategies. This safety feature provides a backup that can enhance peace of mind and potentially improve the effectiveness of self-care.

Further, the utility of VR varies based on self-care objectives and user attitudes. Overall findings showed four types of self-care objectives. Users may employ VR to: (i) alleviate feelings of sadness through relaxation, briefly disconnecting from one's current stressors or negative emotional states, and by experiencing positive emotions; (ii) actively process and manage emotions, seeking solutions and learning skills to better cope with future challenges; (iii) leverage a neutral mood to enhance self-awareness, enjoy hobbies, or build resilience; and (iv) further consolidate and enhance happiness when already being in a positive state of mind. However, these self-care objectives have to be met with an open-minded attitude. Merely using the methods outlined in this dissertation to avoid issues or for entertainment may prove ineffective. In contrast, strategically employing these methods to create mental space for processing emotions and introspection can significantly support the resolution of real-life challenges.

Additionally, the users' character and personality can affect the effectiveness of self-care practice. Users prone to overthinking and rumination should approach VR-based self-care with care, as this tendency can reduce mental capacity and perceptiveness for VR-based self-care to be effective. Entering VR while already caught in an emotional thought cycle could potentially result in harmful outcomes, such as increased rumination rather than productive self-reflection. In these cases, engaging in non-technical activities such as taking a walk in nature or physical exercise can be beneficial, as these activities release serotonin and can potentially enhance mental clarity. Afterwards, VR-based self-care could be more effective. Users should also be informed about the range of movement involved in VR experiences to prevent injuries due to being deeply engaged, which could result in overlooking safety boundaries.

Strengths of Self-Creating Virtual Environments

Drawing is an *engaging* and joyful activity in itself [275]. With the focus on positive affect, it can hence be considered a "positive emotion-focused strategy" [548]. This was consolidated by the findings of this dissertation, where participants overall enjoyed using the VR drawing tool. The process also facilitated a state of flow. Users reported being fully immersed and present in the virtual space, losing track of time, experiencing positive emotions such as joy and engagement, and finding self-creation effortless, aligning with the related research on the benefits of flow [142, 244, 383].

Further, while the method of self-creation was primarily designed to foster autonomy, it was also found that it enhanced users' sense of *competence*, addressing another psychological need [483]. The VR drawing toolset "makes everything look pretty", as one participant emphasised, which counteracted previous self-doubts in regard to the ability to express oneself creatively. Further, mistakes are easily reversible, allowing users to freely experiment without the sense of permanence often associated with traditional art making [276]. Thus, even users who claimed that they would never use artistic tools for self-care due to lack of creativity were proud of the resulting virtual environments and stated the intention of repeated use.

Additionally, self-creating the virtual environment was not only perceived as enjoyable, but it also empowered users to ascribe meaning to the spaces. Hacmun et al. [237] described it as an "imaginary experience of the unreal that is made possible through VR", by engaging kinesthetic, visual, and aural senses and seeing the VR drawing from multiple spatial perspectives. Oftentimes, this fostered a sense of ownership, as participants referred to their creations as "my" virtual space during interviews. It is moreover evidenced by participants' desire to preserve their autonomously created spaces in virtual catalogues, show them to friends and take reminders back into the real world (*D - MoodWorlds*, *F - MoodShaper*).

Self-creation also facilitated self-reflection and introspection. To that end, the main strength lies in offering a playful and "messy" tool, which made complex emotions more tangible and less intimidating for participants, particularly when dealing with negative experiences, as in *F - MoodShaper*. This approach can create mental space for users to reflect on themselves, their emotions, and their situations, leading to enhanced self-knowledge and cognitive change, at least for some participants.

Challenges of Self-Creating Virtual Environments.

However, the method's open-ended nature sometimes presented a *mental barrier*. Despite prior tutorials and a simplified version compared to pre-existing VR drawing tools such as OpenBrush [6], some participants still felt overwhelmed by the complexity of the toolset, on top of the intricate task of visualising internal states. Contrarily, participants also often desired more variety in pre-set environments, 3D objects, and animated brush types, highlighting that even an open-ended tool could still be optimised for individual preferences.

Further, the approach of drawing in VR is time-consuming, which can lead to physical and mental fatigue. When this method is accompanied by other strategies, such as visual metaphoric actions for emotion regulation as seen in *F - MoodShaper*, it might draw energy away from the focal point of the intervention. Thus, the self-care objective should be clearly communicated to users.

Another interesting tension concerns the balance between a playful and engaging approach versus following more serious self-care objectives, such as self-reflection and self-awareness. Over-engagement can happen due to gamified elements [405, 636] that can foster a sense of flow, which can distract users from pausing to reflect [266, 428]. Thus, gamified elements, such as scoring systems, rewards, visual progress bars and possibilities to level up, should be carefully aligned with self-care goals to ensure that they do not hinder the enhancement of introspection [405].

In the design process of the prototypes of this dissertation, we decided not to employ gamified elements, primarily as they provide an extrinsic externally-controlled form of motivation [482], which conflicts with the goal of enhancing autonomy. While gamification can be successfully applied for self-care [550], it can also increase pressure and stress and might encourage superficial engagement with self-care practices. This can impede personal growth [119], a key objective of this dissertation. Thus, we designed playful and ludic elements. Despite this, similar risks were observed. Participants in *D - MoodWorlds* mentioned becoming overly engaged, losing focus on self-care objectives as they were drawn more to the enjoyment of drawing than to reflective introspection. In these cases, more structured guidance, such as hands-on scaffolding, could nudge users to re-focus on self-care objectives.

Managing Everyday Emotions and Challenges

One aim of this dissertation was to explore possibilities of how VR can be effectively designed to support laypeople in managing emotions and challenges of daily life. In that regard, the method of autonomously self-creating virtual spaces was used for visualising a range of emotions, including positive emotions based on a positive autobiographical memory (*D - MoodWorlds*), past emotionally challenging experiences (*E-SelVReflect*), and negative emotions based on negative memories (*F - MoodShaper*). Reflecting on overall findings, it is insightful to discuss how self-creation can influence the emotional tone of memories expressed through it and to identify potential use contexts based on these effects.

To explore the impact of autonomously self-creating virtual environments on the emotional valence of memories, it is important to understand how the brain encodes and recalls memories and their associated emotions, and how these memories may change when revisited within VR-based self-care scenarios.

To that end, scientific studies showed that high-arousal experiences, whether positive or negative, are more memorable than neutral ones [280]. Being emotionally involved triggers chemical processes in the brain, signalling these experiences as significant and thereby integrating them into a so-called "core" emotional memory network [280].

Strong negative experiences are mostly very durable and fade only a little over time and are often memorised in great detail [280]. This is attributed to the brain's use of sensory processes during encoding, allocating more cognitive resources to these experiences because they demand caution and precision [280]. In contrast, positive experiences are memorised in less detail, as they are encoded as conceptual processes that broaden attention and emphasise the focus on heuristics [280]. While they are recalled more frequently, the emphasis is on re-experiencing the affective intensity, which can serve as rewards, rather than recalling the specific details of the situation [628]. In sum, this suggests that while people generally recall positive experiences more frequently, negative memories tend to be more vivid and prominent when remembered. In regard to VR, both positive and negative memories were found to be effectively recalled and impact the in-the-moment emotional states of participants [220, 234].

Research mainly focuses on studying memories of negative experiences [628]. Mostly, negative emotions as used as initial starting points in studies, which may be attributed to their higher memorability and durability [280]. Another factor might be that it generally seems to be easier to induce negative emotions in studies [38]. This phenomenon may be attributed to participants typically entering a study with a neutral or positive mood, which establishes the baseline for the experiment [38]. Enhancing this already positive mood with an intervention can be challenging compared to initially inducing a negative emotion and then improving it to a positive one [38]. This approach does not only result in more significant changes in data analysis afterwards but is also logical when the self-care activity's overall aim is to improve users' moods, as, for example, demonstrated in *F - MoodShaper*.

Recalling negative experiences when being in a positive mindset can help to positively reinterpret these memories, updating them with a sense of positivity in the process [548]. This can enhance mental well-being [548]. Essential for this reinterpretation is to have a "positive emotion-focused strategy" [548]. Based on comprehensive insights from this dissertation, the process of autonomously creating virtual environments can act as such, as it stimulates positive affect and engagement through drawing and self-expression [275]. As tested in this dissertation, this method can be extended by strategies such as voice-based guidance (*E - SelVReflect*) and visual emotion regulation (*F - MoodShaper*), which proved effective in promoting cognitive shifts related to the visualised emotions and experiences.

As a side note, although the method generally enhances positive emotions, prolonged immersion in virtual environments depicting negative experiences can still re-induce negative feelings. Therefore, incorporating clear visual closure as a scaffolding element could prevent users from reverting to a negative state of mind after successfully transitioning to a positive mood.

In addition to reinterpreting negative experiences positively, engaging with positively associated memories can help preserve them more effectively. While neutral experiences are easily forgotten, positive memories also tend to fade relatively quickly over time [280]. Preliminary findings of related work suggest that reconstructing past events in VR, being immersed in them and interacting and engaging with them, could lead to better preservation of the memory in richer detail [**?**]. Utilising a "positive emotion-focused strategy" [548] such as self-creation in VR has the potential to better preserve these memories, shifting them into the "core" emotional memory network [280]. Insights from *D - MoodWorlds* hinted at this possibility, as participants expressed a desire for a virtual catalogue for later memory recall. However, further research is needed to validate whether VR and its drawing toolkit can fully realise this potential. If proven effective for preserving positive memories, this tool could not only promote relaxation and positive feelings but also strengthen cherished memories in the long term.

Structured vs. Open-Ended Approach

In order to design VR-based SCTs that facilitate self-care practices for laypeople in their everyday routines, the aforementioned sections have primarily reflected on methods and features that provide engagement and scaffolding to make self-care activities more effective. Thereby, this dissertation overall has taken an explorative approach, granting participants a lot of autonomy and freedom in studies, such as by providing options for self-creating virtual environments.

By emphasising user autonomy during all my studies, this dissertation diverges from typical HCI research. Apart from a few exceptions (e.g. [28]), the majority of studies adopt a paternalistic approach, often prescribing virtual environments (e.g. [38, 388]) and limiting interaction to reduce confounding variables (e.g. [292, 369]). Especially in mental health VR applications, highly structured approaches are common [431, 321]. They ensure safety, control, and adherence to clinical guidelines and regulatory standards. These designs prioritise replicable and effective therapeutic outcomes, aiming to provide a predictable user experience to minimise risks for individuals sensitive to unexpected stimuli [431, 321].

Yet, comprehensive findings from this dissertation have demonstrated the value of moving away from strict rigidity and regulatory constraints. While structure can be essential for clinical contexts, open-ended approaches promise a lot of benefits for supporting mental well-being. Despite losing some advantages of a structured approach, such as comparability, embracing more open interactions akin to art therapy can offer new avenues for self-awareness and self-care. While autonomy in technology design was pronounced an important factor as early as its inception [106], I argue that not enough focus has been placed on specifically developing VR-based mental well-being support prioritising user autonomy over predictable user experiences - a research gap that this dissertation has addressed. I aim to inspire the inclusive design of well-being technologies that empower users to identify their own needs and then support their self-care endeavours. This approach avoids imposing a normative ontology that dictates which strategies to use and which virtual environments to engage with, as discussed by Spiel et al. in their study on fitness trackers [549].

3.1.2 Revisiting RQ1 - Key Design Challenges

RQ1 was dedicated to defining the current key design challenges of VR technology aiming to provide self-care for untrained people. To address this, we conducted an application review of VR-based self-care applications available in the consumer market, using expectations from mental health professionals as a lens for investigation. Based on derived mismatches between expectations and offers from consumer applications, we developed a clear understanding of current research gaps in regard to VR-based SCT.

To increase effectiveness, more focus has to be placed on providing options to customise content. Additionally, VR applications should provide psycho-educational features that promote learning and scaffolding for skill development. At the same time, they should also offer an affective approach, supporting users in gaining an emotional benefit from the experience. It was highlighted by mental health professionals that engagement is an important factor in creating effective interventions, and consequently, ludic aspects could be integrated to improve the user experience. We also recognised the importance of initially establishing a virtual safe space. This is taking to fostering a relationship between therapists and clients towards the beginning of clinical therapy. Feeling safe can enable users to be more mentally prepared and available for introspection and self-care.

Another key challenge is designing self-care applications that are risk-free and inherently safe. Mental health professionals reflected on the possibility of rumination or re-introducing traumata when using VR for self-care in an unguided way (*A - AppSurvey*). To mitigate this, they proposed that applications should clearly present risks and limitations, pointing towards professional help if needed. The importance of designing in a safe way was also emphasised by experts taking part in *F - MoodShaper*, as well as participants of studies presented in paper *D - MoodWorlds*, *E - SelVReflect* and *F - MoodShaper*. We found that the current infrastructure of available VR applications for self-care in the consumer market seldom matches those requirements (*A - AppSurvey*). Instead, they are mostly dedicated to providing relaxing and meditative experiences.

Two further key design challenges can be established that both stem from the notion that technology should not replace human support [128]. The intrinsic value of social interaction and human compassion is irreplaceable [128]. Despite technological advances like AI-driven personalisation and physiological sensing, VR cannot (yet) replicate the nuanced empathy and connection provided by interactions with friends or therapists.

Yet, seeing these advances, many mental health professionals expressed concern about being replaced by technology, leading to a cautious and critical view of new technological advances such as VR-based self-care aimed at laypeople without professional assistance. To address these concerns, therapists could be integrated into the design processes of SCTs. This approach might help mitigate their fears by highlighting the technology's potential to complement, rather than replace, human support systems. This implies also another design challenge addressing laypeople. SCTs should clearly communicate their capabilities and associated risks, emphasising that they are not intended to replace professional help or social networks.

These findings highlight the need to further explore how to leverage the unique affordances of VR to implement these guidelines. For instance, how should a safe space look and feel to the individual? More research on how to design in an effective and safe way is essential, both in regard to the virtual environment, as explored in *Designing the Virtual Space* (Part III), and in regard to scaffolding elements for guiding the user experience, which was the focus of *Designing the Virtual Scaffolding* (Part IV).

3.1.3 Revisiting RQ2 - Designing the Virtual Space

To address RQ2, **How can the virtual space be designed to promote introspection?**, I contribute three prototypes and empirical user studies designed for and evaluating the impact of different sensory modalities - haptic, auditory, and visual - on aspects of introspection.

Reflecting on Modality Usage in Regard to Self-Care Goals. We discovered that tactile feedback enhances self-awareness by deepening the understanding of one's body and internal states. Ambient sounds promote presence and self-reflection, whereas other sounds, like footsteps, rather distract from the self-care objectives. The visual environment also significantly impacts users. For mindfulness tasks, it could be aesthetically pleasing yet simple to minimise distractions. For self-reflection, incorporating a single, impactful element like realistic weather proved effective in stimulating and engaging users in the self-care task. For self-expression, visuals can be abstract or even chaotic, as long as they foster a sense of connection between the users and the virtual environment.

Thus, our findings suggest that virtual spaces should be tailor-made for specific self-care activities, with a careful balance of modalities. Greater realism is not always beneficial, and sometimes introducing additional modalities, such as footstep sounds, can hinder the effectiveness of self-care. However, this thesis could not explore all modalities or variations within a single modality for every self-care activity, indicating a need for further research. For instance, while tactile feedback has proven effective in centring individuals and fostering self-awareness, its role in emotion regulation remains to be explored. Moreover, other forms of haptics, such as active haptic feedback, have not been investigated so far.

Reflecting on Self-Creating the Virtual Space. In our exploration of virtual space design, we also examined the impact of users self-creating their virtual environments. The findings from *D - MoodWorlds*, *E - SelVReflect*, *F - MoodShaper* consistently emphasised the value of self-creation in regard to the following: The spaces thus created became more meaningful (which is especially important when creating safe spaces), sense of ownership increased and self-care activities conducted in this space became memorable for users. Our findings align with existing research indicating that the variety of colour and its saturation influence how positive a virtual space is perceived [412, 418], and with natural VR settings often used to represent happiness and provide emotion-enhancing environments [155, 227]. Conversely, VR spaces designed to evoke negative emotions typically featured urban environments or constrained movement, such as locating oneself within confining cage-like structures or above a fear-inducing abyss, mirroring set-ups used in exposure therapy [365, 475].

However, some participants deviated from the norm and common associations. For example, they chose dark and empty backgrounds not to express negative emotions, but to enhance the vibrancy of colours. A dark backdrop allowed them to better engage with their thoughts in "an empty void" (P9 in *E - SelVReflect*). Furthermore, participants noted that the darkness provided a backdrop distinctly different from their real-life surroundings. This separation enables them to distance themselves from their everyday environments, allowing for a fresher, more objective approach to their emotions.

The individual associations highlight another key finding: the importance of context in evaluating virtual spaces. As illustrated by the following example of *C - Veather-Reflect*, sunny weather generally correlated with positive emotions and low stress. Yet, some participants had negative associations due to past experiences with droughts, expressing a desire for customisable weather settings instead. This variety underscores the critical role of personal context and preferences, highlighting the benefits of autonomy in design decisions.

The value of using virtual 3D objects to inhabit virtual spaces varied among participants, with some preferring to draw elements such as trees themselves despite the availability of corresponding 3D objects, to add a personal touch. In general, background, colour, and lighting seemed to be more influential for meaningful virtual spaces than 3D objects, with two notable exceptions. First, participants frequently used abstract objects like hearts to represent people, favouring metaphors over potentially inaccurate avatars. Additionally, there was a strong preference for objects that held personal meaning, such as pets or favourite chairs, emphasising the need for more customisable options in virtual environments to enhance personal relevance and autonomy [266].

In summary, findings related to RQ2 highlight the critical role of virtual space design in creating emotional, meaningful, and effective self-care experiences. Colours and backgrounds, for instance, scenery or plain black, are particularly impactful in evoking and visualising emotions; however, their effect varies significantly based on individual preferences and contextual factors. While allowing users to autonomously create their virtual environments addresses diverse needs, it also introduces specific challenges.

3.1.4 Revisiting RQ3 - Designing Virtual Scaffolding

The previous parts have highlighted the need for guidance and support systems to make self-care activities safe and more effective. RQ3 specifically explored: **How can VR scaffolding be designed to facilitate self-care practices and engagement?** This dissertation conducted two user studies to explore different forms of scaffolding.

Drawing on research related to conversational interfaces, we developed voice-based scaffolding that posed questions to promote self-reflection and offered positive affirmations. It provided encouragement and suggestions but without giving instructions. We found that this approach was perceived beneficial to guide through complex tasks such as expressing a personal challenge, especially for people who were not as open to communicating their emotions. Yet, it was challenging to design verbal scaffolding in a way to not instruct but to inspire and encourage aspects of introspection and to find the right timing to not disrupt the flow of participants.

We further explored three ways of providing visual scaffolding through metaphoric actions in VR, aimed at prompting cognitive change through applying emotion regulation strategies. We found that visual scaffolding carries the risk of misinterpretation. Interpretations of the meaning behind the visual metaphoric interactions varied widely, with some even contradicting the intended meaning. Yet, all forms of understanding ultimately supported users' self-care journeys as they were adapted to fit users' individual needs at that moment. Thus, even when misinterpreted, they offered effective guidance. This underscores the importance of providing multiple scaffolding options that users can select from on a daily basis, tailored to their specific needs at any given moment.

Interestingly, I also found that the procedure of a self-care application can serve as a scaffolding element. The application's structure can facilitate self-care goals. For example, gradual transitions into and out of VR can support becoming self-aware and incorporating repetitions of emotion regulation strategies (such as repeatedly throwing paper planes) allows for time to internalise them.

Overall, I learned that both verbal and visual scaffolding represent a form of extrinsic motivation, but that still targets autonomous regulation as it was perceived as a tool that helps users to achieve their own goals (see Figure 2.3). I found that it can be used to simplify tasks, guide through the intervention, teach strategies and make self-care more effective. Through this approach, scaffolding can enhance engagement. However, excessive scaffolding can also diminish engagement by disrupting user flow and limiting autonomy, as users may become overly reliant on guidance rather than exploring their own solutions. This underscores the need for careful design to maintain the right balance.

3.2 Design Recommendations

One strength of this dissertation is the ability to offer precise design recommendations that are applicable across a spectrum of VR-based self-care activities, and fundamentally motivated by enhancing user autonomy. Hence, this section will provide four design recommendations based on the comprehensive findings of this dissertation that address how to design (i) beyond the intervention, (ii) for multilevel customisation, (iii) for meaningfulness and (iv) to counterbalance the valence of experiences.

Designing Beyond the Intervention

There is a cyclical relationship where users who feel engaged are likely to have a more positive user experience [165, 571], which in turn encourages continued engagement and satisfaction[288], further fulfilling their psychological needs [482]. However, it is important to understand that the period of interaction makes up one component of the full user experience . Drawing from real-life therapeutic practice, the phase before and after self-care activities are essential to building trust between therapist and client, which forms the basis of effective therapy [115, 246, 446].

Furthermore, the impact of applications extends beyond the completion of the actual technological intervention. For instance, people reflect-on-action [511] and might experience hermeneutic (perception-changing) and pragmatic (behaviour-changing) effects triggered by the application [596]. Importantly, technologies can be designed to facilitate reflection, influence cognitive changes and promote behaviour change[596]. Further, Nunes et al. [405] have already established that the design of SCTs should go beyond treating the medical aspects of a condition, emphasising to consider how a SCT can fit into people's daily activities and become part of their lived experience.

Based on these insights, this thesis contributes specific design recommendations and design ideas considering pre- and post-intervention phases when designing VR-based SCT. Concrete design recommendations in that regard are discussed in the following.

PRE-Intervention Phase. Through interviews with mental health professionals and users from papers *A - AppSurvey* and *F - MoodShaper*, I found that VR-based self-care applications should focus on putting users at ease before starting the intervention. Engaging in self-care, especially when regulating strong negative emotions, can trigger anxiety and stress merely at the thought of managing them. Users require reassurance that there are no negative consequences or guidance on how to handle unforeseen challenges. For example, applications could provide links to human support systems as one option or suggest strategies applicable in non-VR settings that can improve well-being, such as enjoying nature [17]. Feeling comfortable with the application can increase users' mental readiness and engagement with the self-care intervention. Consequently, by addressing safety and security concerns, the effectiveness of self-care activities can be improved.

One other option that can increase the safety and effectiveness of self-care applications is incorporating a risk notice, as identified in paper *A - AppSurvey*, *C - VeatherReflect* and *F - MoodShaper*. Prior to starting the application, this risk notice would inform users about possible dangers such as the induction of negative emotions or being reminded of emotion-evoking personal events. This would make users aware of potential harm and reflect ethical design considerations from the VR developers, potentially convincing users to choose this application due to the careful and serious handling of these aspects.

However, risk notices should not intimidate users, as this could inadvertently increase anxiety, thereby undermining the objective of offering reassurance. As an example, in paper *C - VeatherReflect*, participants were informed via text before starting the study that they would be immersed in visualisations of their stress levels, which could potentially affect them on an emotional level. In that particular case, it rather increased the curiosity of users. The question remains how to design transparent communication of possible risks that people would actually read (see similar challenges in regard to reading privacy policies [559]) without increasing anxiety. This motivates future research.

Findings further underscore the importance of clearly communicating the objectives of the self-care application to help users anticipate what will occur. This can reduce uncertainty and enhance the effectiveness of the intervention. For instance, participants of studies detailed in papers *D - MoodWorlds*, *E - SelVReflect* and *F - MoodShaper* uniformly mentioned that one reason for the effectiveness was attributed to the coupling of the VR autonomous drawing tool with a clear objective and meaningful purpose. Specifically, the objectives were to create a positive space (*D - MoodWorlds*), visualise personal challenges (*E - SelVReflect*) and visualise a negative space (*F - MoodShaper*). Particularly concerning the latter two interventions, the clear intent that participants had from the outset suggests an enhancement in the perceived effectiveness of the intervention, as indicated by qualitative reports from these studies.

Notably, the aforementioned aspects, such as creating a comfortable environment and clearly communicating self-care objectives, also mentally prepares users, even when the application aims to elicit positive emotions and relaxation (hedonic-focused). Even in the absence of self-care goals such as managing complex negative emotions, the pre-phase is thus important and can influence users' selection process.

In addition to the findings presented in this dissertation, related studies have also highlighted the importance of establishing trust in privacy and confidentiality in the security and processing of user data during the pre-intervention phase [164, 551]. Effectively, when navigating the decision of which application to use, being transparent in the communication about these aspects could nudge users towards selecting an application.

While the findings presented here are from this dissertation, related literature further underscores the importance of building trust in privacy and data security during the pre-intervention phase [164, 551]. This should be additionally considered when designing the Pre-Intervention phase.

POST-Intervention Phase. Similar to the pre-intervention phase, applications should also proactively compensate for potential adverse effects post-intervention. For instance, users may experience discomfort due to technical malfunctions, or personal issues that diminish the intervention's effectiveness. Further, applications can also be used in unintended ways, called the multistability of technologies [596]. As a solution, experts interviewed in the study of paper *A - AppSurvey* suggested actively linking towards further support, for example, to point out helplines or therapeutic support. This finding is in line with related work, which emphasised that technologies cannot replace, only augment, human support systems (e.g. [128]).

Furthermore, findings indicated that being reminded of reflection-in-action afterwards triggered reflection-on-action. As an example, in *E - SelVReflect*, voice-based guidance is employed during the intervention to encourage deeper reflection in users, and to facilitate reflection-in-action. During post-test interviews, numerous participants recapitulated the insights gained from reflection-in-action, iteratively reflecting on them, demonstrating reflection-on-action. This validates existing literature indicating that reflection-on-action increases the effectiveness of reflection-in-action [74]. However, in non-study settings, there would be no interviews triggering reflection-on-action. As alternatives, participants in *D - MoodWorlds* envisioned a virtual memory book or catalogue to serve as a reminder of their experiences and moments of personal growth. Participants in *F - MoodShaper* developed the concept further by envisioning a tangible reminder to bring into the real world, such as a decorative pillow that mimics the texture of the virtual safe space. Additionally, I propose establishing a link with a physical screen that could display the most recently created virtual environment to the user. In addition to prompting reflection-on-action, this approach could overcome another common barrier of SCTs, namely that people often lapse in usage simply because they forget to engage in self-care activities [405].

Based on my own findings and in line with related work, I propose the following design recommendation for VR-based SCT:

Recommendation 1—Design beyond the intervention. This involves ensuring transparency about intentions and risks, communicating the rigorous protection of data integrity and privacy before the intervention, providing links to additional human support, and incorporating ongoing and retrospective reflection after application usage through tangible reminders.

Inter- and Intra-Personal Diversification

Related work keeps on emphasising the need to diversify the spectrum of self-care activities and functionalities [135]. They have pointed out the need for more adaptable systems [135, 164] that allow to better take the individual user experience into account [405]. The resulting personalised SCTs would be able to incorporate users' routines, task complexity, environmental factors, a mix of different tools used for self-care, physiological real-time measured data, personal backgrounds and cultural differences such as education, available social support networks or cultural beliefs [135, 86, 164]. Moreover, the findings from this dissertation also highlighted that the selection of self-care strategies and the design of virtual environments are influenced by the individual's mood at that particular moment and the intensity of the emotions they wish to visualise and manage. For example, some participants in *F - MoodShaper* found the paper planes effective for managing sadness but less so for anger.

Despite taking all these considerations into account, users might still potentially utilise the intervention in ways unintended by designers, relating to the term multistability as coined by Verbeek [596]. This calls for general considerations of overall ethical and safe design [596], to compensate for possible unforeseen circumstances.

While it is widely acknowledged that designing SCTs must accommodate inter- and intrapersonal differences, this dissertation suggests that a *single* VR application can be designed to address multiple aspects of self-care, addressing many of the aforementioned intra- and interpersonal challenges, and mitigating problems due to the multistability of technology. This becomes possible, first, by involving users in the technology design process (as advocated in Human-Centered Design [96]). Second, customisation options play an essential role, such as allowing users to create their own virtual environments (as demonstrated in papers *D - MoodWorlds*, *E - SelVReflect*, *F - MoodShaper*), and selecting strategies they wish to practice (e.g. choosing metaphorical actions for emotion regulation they find suitable at that specific moment, a finding from *F - MoodShaper*). To this end, the ability to adjust and self-create virtual environments in real-time offers a unique form of customisation. It allows users the flexibility to change their minds and adapt their surroundings to evolving emotions, distinguishing it from more static customisation options. However, the aforementioned options only increase the *potential* to accommodate both inter- and intra-personal preferences. It is worth noting that other approaches may also prove equally effective.

Recommendation 2—Design for multilevel customisation. Embrace diversity in various self-care activities and within specific interventions, accommodating individual preferences and those specific to each use case.

Designing for Meaningfulness

Related work has shown that feelings of presence can function as a catalyst for effective interventions. High presence in VR positively influences concepts related to self-care, such as mindfulness [389, 513], agency [267], emotions [267, 462] and general user experience [504, 571]. This is in line with my findings from paper *B - Haptics*. It showed that presence was significantly increased by ambient sound and haptic feedback aligning with visual stimuli, making mindfulness tasks more effective.

Further, my findings revealed a notable tension between the appeal of realistic virtual environments versus more abstract, minimalistic or cluttered designs. In regard to the first, related research has noted that high realism of virtual environments can increase presence [536]. This has also been shown by the findings of this dissertation as well. Participants mentioned the positive impact of realistic environments on self-awareness aspects. For instance, participants in the *B - Haptics* study noted the positive impact of a beautiful landscape on mindfulness, confirming that a virtual environment simulating nature can have a relaxing effect on users. (e.g. [155, 227]). Similarly, participants of *C - VeatherReflect* positively noted the positive influence of highly realistic weather scenarios on engagement and self-reflection. They reported that the virtual weather elicited strong emotional responses and, on occasion, they also experienced perceptible physical effects. This is in line with other works leveraging the emotional and physical effect that VR can have on people (e.g. [190]).

However, participants also enjoyed minimalistic, clean and non-distracting virtual spaces for self-awareness, especially for mindfulness tasks (paper *B - Haptics*). This is in line with prior research, showing that too much detail can re-introduce distractions and diminish the effectiveness of interventions [159, 391]. Consequently, there has to be a balancing of design trade-offs and research objectives [391].

Notably, participants also found being immersed in abstract and "messy" virtual environments to be effective for self-care (paper *D - MoodWorlds*, *E - SelVReflect*, *F - MoodShaper*). One participant described using the toolset for self-creating the virtual environment as experiencing "childlike clumsiness". On the one hand, this highlights that despite the low interaction fidelity of the drawing tools, they still enhanced joy and engagement, consistent with prior research [264]. On the other hand, it underscores that also non-realistic, minimalistic or chaotic virtual spaces can promote effective self-care. Across all three studies, participants considered these virtual spaces as personal, intimate, and significant, expressing pride in and a desire to remember them. These responses indicate an emotional attachment to the space and a strong sense of ownership. This outcome most likely stems from being empowered through self-creation. Some scholars even consider an emotional connection and agency more important to create presence than the realism of virtual environments [267].

Thus, findings regarding the importance of realism for effective VR-based self-care applications vary a lot. The studies included a range of virtual environments, from highly realistic with the integration of numerous modalities, over realistic but minimalistic, to abstract and childlike virtual spaces, all of which were found to be effective for specific self-care activities. I would argue that varying levels of realism can engage people, sometimes facilitating effective self-care while hindering it at other times. Instead, I propose that meaningfulness emerges as a key factor for the design of virtual spaces aiming to create effective self-care activities. As long as users feel emotionally connected to the virtual space and derive personal significance from it, self-care appears to be effective, and it enhances the potential for continued use. Hence, I derive the following design recommendation:

Recommendation 3—Design for meaningfulness. Balance sensory modalities input with specific self-care goals to avoid over-complexity or distraction and enhance the focus on creating meaningful interventions.

Counterbalancing the Valence of Experiences

Experiences of daily life have a range of emotions connected with them. This dissertation has shown that the strategies and procedures of self-care activities can be adjusted to counterbalance the valence of those emotions.

Addressing negative emotions, as demonstrated in *F - MoodShaper*, is a self-care objective that is associated with a sense of seriousness and emotional heaviness. It can elicit strong negative emotions when engaging in emotion regulation in VR [220, 234].

People often approach the complex and intimidating task of managing negative emotions with a sense of urgency and focus, driven by an intrinsic motivation to improve their mood. To elaborate, experiencing positive emotions triggers biological responses, such as the release of dopamine and serotonin [259, 261]. These chemicals provide immediate pleasure and promote behaviours that heighten the likelihood of experiencing these positive feelings again. Thus, intrinsic motivation and subjective well-being are positively correlated, as also highlighted in a study by Grassinger et al. [222]. This underscores a cyclical process where motivation to engage in self-care activities that enhance mood, in turn, encourages individuals to participate in these activities more frequently. As such, experiencing positive emotions is fundamentally linked to enhanced mental well-being and greater life satisfaction [484].

To support people in this self-care goal, VR-based self-care applications should especially target a playful and engaging approach to offset the inherent seriousness of the topic. In other words, "the childlike capability [of self-creating the virtual space] feels like a safe way to engage with your emotional state" (P61 in *F - MoodShaper*). Given that individuals often have a strong intrinsic motivation to improve their mood when they are feeling down [484], less hands-on scaffolding is required to guide them towards this goal. Instead, high-level reflective scaffolding could focus on encouraging self-reflection and cognitive change and to prevent rumination, as these will promote positive emotions and mental well-being.

In contrast, when people are already in a positive state of mind they often have less intrinsic motivation to enhance their positive emotions even further. However, self-care activities aim not only to induce pleasure (hedonic focus) but also to promote introspection and skill development (eudaimonic focus). Nonetheless, given that intrinsic motivation is lower and the consequences of not achieving these additional self-care goals are less critical (i.e., individuals would remain in a positive state of mind, even if they have not gained new insights), there is a greater need to intrinsically motivate that also those self-care objectives are met. Thus, more structured scaffolding is needed.

To illustrate, the method of self-creating virtual environments visualising positive internal states as evaluated *D - MoodWorlds* could be used to reflect on the nature of happiness, explore what happiness feels like, and identify who and what contributes to it. This process aimed to enhance self-awareness, self-reflection and deepen self-knowledge. While this was the outcome for some participants, others were so engaged that they enjoyed the experience without gaining deeper insights. Thus, when the self-care task is easier to accomplish, straightforward, and less emotionally taxing, more scaffolding elements could be included that prevent over-engagement and re-focus users on gaining introspection [266, 428]. Based on the findings pointing towards balancing engaging and scaffolding elements, I recommend the following:

Recommendation 4:—**Design to counterbalance the valence of experiences. On the one hand, integrate playful elements to enhance engagement when managing complex emotional tasks and heavy topics. On the other hand, provide structured scaffolding for simpler tasks to prevent over-engagement and direct users' focus towards the self-care objectives.**

3.3 The Self-Care Technology Process Model (SCTpm)

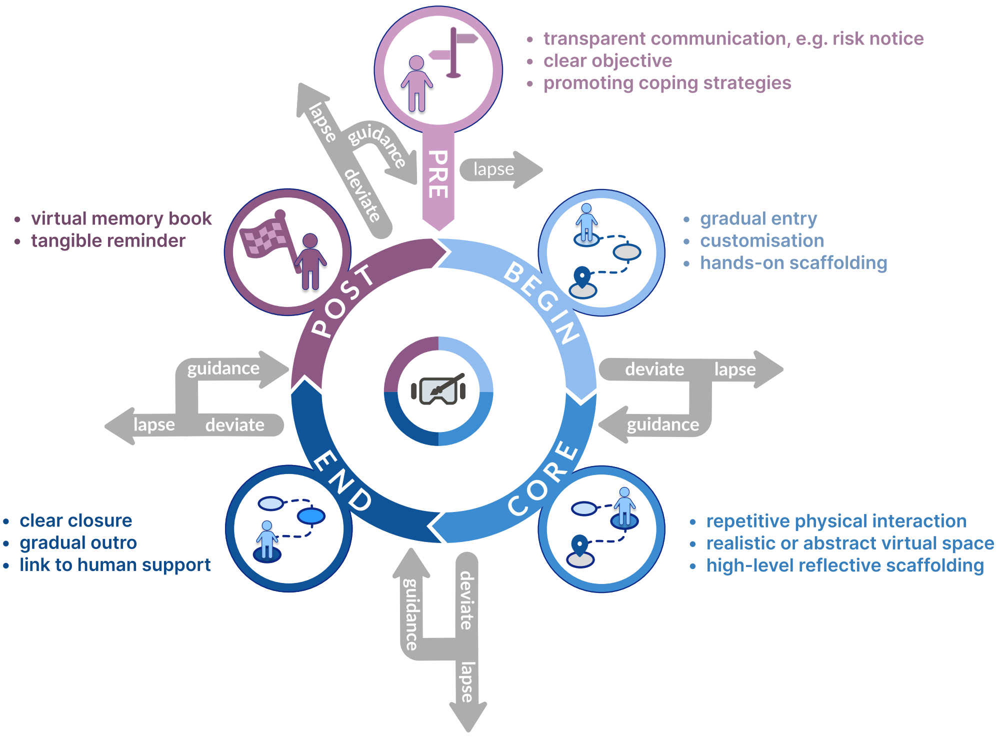

Figure 3.1: This Self-Care Technology Process Model (SCTpm) represents the phases a user experiences when using a self-care application. Tailored design decisions at each phase can support the user to maintain engagement and ensure continued use.

This dissertation extends beyond surveys, interactive artefacts, and empirical user studies to offer a theoretical contribution [633]: the Self-Care Technology Process Model (SCTpm). This model provides a detailed framework for an intervention-centered self-care journey, emphasising key design decisions that enhance user engagement and prevent lapsing. It supports SCT designers in the iterative design process by presenting targeted design ideas tailored to meet phase-specific user needs and which can promote sustained interaction with self-care applications. Thus, the SCTpm offers a new perspective on user engagement for SCT designers, focusing on the integration of tailored design decisions throughout the self-care journey.

Intended Target Group and Usage of the Model. The SCTpm is designed to support designers developing self-care applications for laypeople. Although primarily based on VR-focused findings from this dissertation, the insights may also be applicable to other self-care technologies like AR, pending validation. This model facilitates the iterative design process in accordance with principles of the HCDP [96] and thus helps SCT designers by integrating design recommendations with a deep understanding of user needs throughout the self-care journey. In this context, *users* refers to end-users (laypeople in a domestic setting interested in engaging in self-care), not to the users of the model (who are referred to as *designers* to avoid confusion).

The Model's Goal. The main goals of this model are to ensure sustained user engagement across multiple phases, enhance the safety and effectiveness of self-care applications, and encourage innovative design.

First, VR-based SCTs should captivate users' attention, encouraging them to traverse all five phases of the self-care journey and ideally, re-iterating the four main phases using the same application. To elaborate, as users progress through their self-care journey, their motivations, goals, needs for information, and desired benefits are likely to change, similar to customer journeys [319]. If users are likely to deviate from the ideal path of the self-care application at any point of the intervention, designers could consult this model to refine their design for that particular phase to guide users back toward the ongoing engagement circle.

Another goal of this model is to support designers in creating self-care applications that are safe and effective. While this can also facilitate ongoing engagement, this implies moral and ethical design such as being transparent with possible risks and refraining from overstating its effectiveness.

Both of the aforementioned goals are addressed by presenting specific design ideas as inspiring starting points. These "puzzle pieces" can be used to experiment during the design process to maximise the potential of ensuring high user engagement and effective and safe self-care activities. Notably, these design ideas are based on personal findings of this dissertation, and can and should be extended based on other literature and future work.

3.3.1 The Model's Description.

The SCTpm was constructed primarily from findings documented in various referenced papers and from the integrated results of this dissertation. This includes design recommendations derived from the findings of multiple studies. Additionally, some aspects of the model are inspired by related literature or a combination of related work and own findings, all of which are clearly indicated in the text.

The SCTpm is structured into five phases: *Pre*, *Begin*, *Core*, *End*, and *Post*, each of

Table 3.1: Throughout each phase of the user's self-care journey, SCT designers focus on distinct objectives and address specific guiding questions through their design decisions.

Phase	Guiding Questions for SCT Designers
Pre	How can the user be made comfortable with choosing this intervention?
Begin	How can the user be introduced to the intervention?
Core	How can the user's self-care aim be facilitated?
End	How can the user be supported in finding mental closure?
Post	How can the user be supported in continued engagement and use?

which will be described in detail below. Typically, a self-care intervention, such as a VR application, includes three main phases (Begin, Core, End), visualised in blue, based on findings of studies such as *B - Haptics*, *D - MoodWorlds*, *E - SelVReflect*, and *F - MoodShaper* and related work (e.g. [14]). Additionally, the three intervention phases are framed by Pre- and Post-intervention phases, depicted in shades of purple. They reflect the extension of the SCT's influence on users beyond the self-care application itself, as detailed described in Section 3.2.

Throughout these phases, users encounter distinct barriers and evolving needs. To address these effectively, SCT designers are equipped with a variety of design ideas, guided by key questions unique to each phase. An overview of these guiding questions for SCT designers is presented in Table 3.1. In the next sections, specific user challenges and design strategies for each phase are discussed.

Pre-Intervention Phase. The self-care journey starts with the *Pre-Intervention* phase, in which interested users select a suitable self-care application. In this phase, one of the key challenges users might face is being overwhelmed by the amount and unstructured presentation of applications to select from [62, 557]. Being unaware of personal needs or fitting search terminology, users face more than 1000 applications to select from. Further, they might feel anxious and stressed in anticipation of the upcoming intervention, in particular when they know that they aim to manage an emotionally challenging task. Thus, the main objective for designers is to reassure users and make them comfortable with the application, subtly supporting their selection process. The following ideas promise relief for users, elaborated on in Section 3.2: incorporating risk notices, communicating clear objectives of the intervention, and providing guidance in the form of real-life applicable strategies, such as promoting a walk in nature or reaching out to a mental health professional if anything unforeseen and harmful should happen. Further, based on related works, being transparent in privacy policies and data confidentiality can help to build trust and influence the choice of application [164, 551].

Begin-Intervention Phase. As users start to engage with the application (*Begin-Intervention*), users initially often face 'blank-page-syndromes', and feel overwhelmed or lost, especially when untrained in visualising internal states. For instance, some participants in *D - MoodWorlds* felt insecure and overwhelmed at the beginning, as they found the task of visualising emotions, as well as the VR drawing toolset complex.

To address this challenge, facilitators are needed that help users operate the VR drawing toolset on a technical level, but also provide support in expressing themselves in a meaningful way [276]. Users could be eased into VR, getting them gradually accustomed to the medium, the specific setting and the interaction controls. This step should not feel like a mere tutorial, but should be integrated in the intervention in an engaging way. For example, as illustratively done in *B - Haptics*, users could visually start in a smaller "safe" space (a hut) in which they have to fulfil some interaction tasks (picking up plates) before transitioning to surroundings where the actual self-care task begins (open meadow, picking up apples, doing a mindfulness exercise). Accounting for inter- and intra-personal differences (see Section 3.2) and for being accustomed to the application due to re-usage, users should autonomously be able to decide when to leave the gradual-entry stage (i.e. the door of the hut is always open).

In this initial phase, customisable options (such as setting a pre-defined background) and hands-on-scaffolding, a more interactive form of guidance, can provide support. Including positive affirmations, encouragement, and detailed guidance (as noted in detail in paper *E - SelVReflect*), they can facilitate enjoyment and create a sense of meaningfulness in this phase (compare Section 3.2), setting the stage and opening the minds of users for effective self-care activities. Due to differences in technical literacy, initial knowledge and mindset (for a detailed discussion. see Section 3.1.1), the duration of this phase can range from just a few minutes to significantly longer.

Core-Intervention Phase. After having become familiar with the interaction techniques and having established a vision of how to approach the self-care objective, users transition into the *Core-Intervention* phase, where main self-care activities such as mindfulness exercises or emotion regulation tasks occur. Here, one of the key challenges is too much or too little stimulation. To elaborate, users may encounter boredom, physical and mental fatigue, or the pitfalls of over-engagement (undermining the effectiveness), or excessive scaffolding (reducing engagement and joy), inspired by integrated findings of this dissertation. Furthermore, as emphasised by therapists and participants across publications, self-care activities for self-awareness (such as mindfulness, findings from *B - Haptics* and emotion regulation, findings from *F - MoodShaper*), require time to take effect. Users need a certain timespan to transition into the right mental state, explore internal states, and acquire new skills that can be assimilated into their daily lives, as found in additional own work [612]. In regard to the time, all studies (except *B - Haptics*) in this dissertation were open-ended, which means that participants could experience the application as long as they wanted. Mostly, their creation of the virtual worlds took between 10 and 30 minutes, including the Begin-Intervention phase. Determining the ideal duration for effective self-care without inducing boredom remains an open question. Generally, due to interpersonal differences between users [86], SCTs could accommodate different usage durations that are still deemed effective.

To address these challenges, integrating dynamic and repetitive interactions that stimulate both the mind and the body has shown to be particularly effective, aligning with the time needed to achieve mental calmness or internalise strategies. I found that a simple and repetitive procedure can aid in self-awareness and skill development (papers *B - Haptics*, *F - MoodShaper*).

Additionally, the environment's design, whether aesthetically pleasing, with ambient sound and haptic feedback, or minimalist and abstract, plays a supportive role in this process and should be tailored to the particular self-care goal (compare Section 3.2). Findings from *A - AppSurvey* also suggest that designs for mental well-being applications should also incorporate physical movement, recognising the holistic connection between mental and physical well-being [520]. For instance, certain motoric gestures and body postures can facilitate cognitive restructuring [456, 612]. Consequently, the procedure of the prototypes used in *B - Haptics* promoted walking around to increase presence, and the ones of *D - MoodWorlds*, *E - SelVReflect* and *F - MoodShaper* promoted spatial perspective taking. Nonetheless, physical elements should not exert users, as is the goal of exergames, for instance [129]. Exertion and fatigue can negatively affect presence and engagement [73]. Based on the specific findings of this dissertation, I recommend using a standing-room-scale virtual environment for VR-based SCTs. Further, the procedure should be designed in a way that encourages moving around and looking at virtual elements or interacting with them, in the case of *F - MoodShaper*, from different angles to encourage mental perspective-taking.

In this phase, there should be a gradual reduction in the amount of scaffolding provided, to facilitate a state of flow. Drawing from flow theory [383], scaffolding could set the optimal balance between skill level and challenge complexity to ensure that the user neither gets anxious nor bored.

Simultaneously, the nature of scaffolding should evolve towards more reflective questions that demand greater cognitive engagement, making efficient use of the users' increasingly enhanced mental capacity to facilitate deeper reflection. Hypothetically, I assume that similar aspects hold true for other aspects apart from scaffolding. For instance, initially simplified interfaces and visually reduced virtual environments could be presented that dynamically introduce additional elements, gradually enhancing complexity to maintain engagement. Taking the example of the VR drawing toolkit, users could first choose a pre-defined backdrop to ease the learning curve for controls and only afterwards allow for the panel of brushes to appear.

End-Intervention Phase. Concluding the intervention (*End-Phase*), the challenge is to ensure that besides task completion users also reach psychological closure; without it, users might ruminate on the experience, which might lead to dissatisfaction and lapsing. To share one example from my research, an instance was observed where technical malfunctioning impeded visual closure and the participant got stuck in the previously created negative emotional world (in *F - MoodShaper*). This impacted the user's ability to achieve mental closure and increased the intensity of negative emotions instead of alleviating them. This highlights the importance of offering visual closure to impact a psychological sense of closure.

For example, users could be presented with a relaxing environment as an incentive, such as a previously created positive space as successfully tested in *F - MoodShaper*. Being finally immersed in a pleasurable virtual environment emphasised the successful completion and achievement of self-care objectives. Other forms of visual closure could work comparably well, for example, fireworks, affirmative quotes, narrative endings or using a person's favourite smell as an incentive. Applications should provide clear closure and celebrate the process of taking care of one's own mental well-being to continue motivating people. Further, a visually progressing outro can bridge the gap between the virtual and real world, such as going back into a virtual room before taking off the VR headset to return to the room in reality, inspired by *B - Haptics*. As an additional safety mechanism, applications could point towards human assistance such as family, friends or therapists.

Post-Intervention Phase. In the *Post-Intervention* phase, users reflect on their experiences (reflection-on-action) and the application's effectiveness, deciding whether to re-engage (re-starting with *Begin-* phase), seek alternative applications or deviate to other SCTs (re-entering the *Pre-Intervention* phase), or laps from self-care completely. The duration of this phase can differ greatly, spanning hours or weeks. Here, design can still influence users' decisions, encouraging continued use. As detailed in Section 3.2, virtual and physical reminders, such as objects or screens displaying their self-care outcomes, can facilitate reflection-on-action and provide motivation for ongoing usage. Tangible reminders might help overcome the barrier of daily life distractions that SCTs face [405]. This consideration becomes particularly crucial for VR-based SCTs, given that they are not as seamlessly integrated into daily routines as smartphones — which can prompt users through notifications — or tangible self-care outcomes like artwork, which can be displayed as a constant visual reminder.

3.3.2 Relating The Model to Relevant Work

This section reflects on how the SCTpm extends and differs from related models and frameworks in HCI research. The aim of this section is not to present an exhaustive list of available frameworks that could be related; rather the aim is to situate the model in the research landscape by juxtaposing it with specific key examples of HCI research and beyond. Naturally, given that my work follows HCD principles [4, 96], the model also encourages core principles of HCD, such as understanding user context and specifying user requirements. My model integrates into steps three and four - designing solutions and testing against requirements - of the HCDP. Specifically, if requirements are not met by the design, thus re-iteratively working on the design solution, my model could help to specify details. To be more precise, it helps to discern *in which phase* users deviate, *which specific user need* was probably not met, and to *find design solutions* to better meet these needs and to counteract further deviation.

Considering existing VR models and frameworks of HCI, there are some that provide design recommendations to support designers in creating effective VR environments and that are linked with aspects relevant for this research. For example, many focus on designing for presence (e.g. [535]), for evaluating modality input in regard to creating realism (e.g. [10]), user experience (e.g. [575]) or regarding the interconnectedness between virtual environments and human behaviours [391]. However, they do not present a specific link to mental well-being. Most frameworks that specifically focus on VR-based self-care, such as the RIOR model [266], address one self-care activity. For instance, the RIOR model [266] provides meta-design recommendations for the optimisation of user interfaces but does not provide concrete design recommendations in regard to the virtual space and how to support users in their self-care journey. Another example is by Zaharuddin et al. [648], who have evaluated the importance of design elements for designing virtual realities suitable for stress therapy. While they provide a list of recommendations, such as the importance of interaction possibilities and of nature-based environments, they did not focus on phase- and user-specific needs and the overall procedure. Others provide design recommendations that consider the evolving needs of users for SCTs in general (e.g., [86, 135, 164]). However, these guidelines generically address SCTs and do not specifically cater to the unique capabilities and affordances of VR. Thus, a model that includes concrete design recommendations for VR-based self-care applications aimed at providing self-care practices for laypeople is needed.

Reality-Virtuality Continuum (RV). The Reality-Virtuality Continuum, originally defined by Milgram and Kishino [367], places reality and virtual reality at opposite ends, with augmented reality and mixed reality in between. In 2021, Skarbez et al. [531] redefined VR as a subset of mixed reality, acknowledging that a complete replication of reality is technologically unfeasible and conceptually unnecessary. This repositioning suggests a more fluid integration of sensory information across the reality-virtuality boundary, such as visibility, audibility, and solidity of real-life objects into VR [298]. For example, this enables interactive experiences such as passive haptic feedback to solidify virtual objects. This could be leveraged to further customise the intervention, embedding personal favourite real-life objects into safe virtual spaces as suggested by Jiang et al. [266]. This could facilitate self-care, relevant for the three intervention phases.

Moreover, the SCTpm proposes that VR-based self-care extends beyond the intervention itself, including pre- and post-intervention phases. While these typically take place in reality, in the Pre-Intervention phase, users might also select self-care applications in a semi-virtual marketplace. Similarly, in the Post-Intervention phase, virtual elements such as self-created VR drawings could be projected into the real-life setting to function as reminders of the successfully completed self-care journey, to display one's artistic work if wanted, and as incentives to continue usage. This dynamic use of the continuum suggests that VR-based self-care applications are not static but evolve with the user's journey, acknowledging the human's individual experience as central, as done in the more recent interpretation of the Reality-Virtuality Continuum [531]. My model indicates that it is possible and even required to shift flexibly along the continuum with a single VR application.

Reflective Practice Theory. Reflective Practice Theory, primarily developed by Schön [511], emphasises the importance of practitioners or designers engaging in continuous reflection to enhance learning and improvement. Schön introduced the concepts of *reflection-in-action*, which occurs during the intervention or design process, and *reflection-on-action*, which takes place after the activity has finished. In the context of users, my model supports *reflection-in-action* during the Begin-, Core-, and End-Intervention phases, as it illustrates that users continually evaluate whether the self-care application meets their needs and expectations. Subsequently, in the Post-Intervention phase, users engage in *reflection-on-action*, assessing the value of the self-care activity's benefits to determine their continued use.

For designers, the model facilitates *reflection-on-action* when observing users deviating or lapsing during design and testing phases. This enables designers to identify phase-specific reasons for these lapses and to develop targeted design modifications to realign users with the intended intervention usage.

Technology Acceptance Model (TAM). Further, the model is related to the Technology Acceptance Model (TAM), which provides a framework to understand how users come to accept and use any form of technology and continued use. Key aspects of TAM are the *perceived usefulness* and *perceived ease of use*. The former refers to how users perceive how effectively the VR-based SCT supports them in their specific self-care objectives. Perceived ease of use describes how well users rate the effortlessness of using the application. Relating to self-care activities, it involves designing for intuitive use, straightforward goals, reduction of cognitive load in regard to usability, and maintaining engagement and satisfaction. Leveraging principles of TAM supports designers in regard to several phases presented in my model. To elaborate, the Pre-Intervention phase profits the most from integrating principles in regard to perceived usefulness, as it can convince people that this intervention will be valuable to them, thus influencing their choice of application. Similarly, it can be important to remind users of the value of the intervention in the Post-Intervention phase. In the Begin-Intervention phase, when users are gradually discovering interaction possibilities and usage of the system, the TAM principle of perceived ease of use TAM can ensure that it is also perceived as easy to use, increasing the likelihood of users transitioning to the next phases. Further, whenever deviations occur in any phase, TAM can help diagnose whether they might be due to perceptions of low usefulness or difficulties in usability, thus providing an additional lens for discerning specific user needs and informing ideas for design solutions that may guide users back to the ideal engagement circle and subsequent phases.

Lived Informatics Model of Personal Informatics. The SCTpm complements Epstein's Lived Informatics Model [184], extending its principles to VR. While Epstein's work was developed mainly for wearables and health data, the core concepts, such as cyclic user engagement, can be applied to my model. In his model, users decide to use and select an application, then proceed to collect data through the application and integrate this data into their daily lives. Through reflection, users interpret this data to gain insights into their health, behaviour and deeper understanding of themselves. This helps to make informed decisions about either continue using the application or lapse if it no longer serves their self-improvement goals. Epstein's phase of *deciding* preempts my model, which does not cover the initial motivation for usage. *Selecting* aligns with my model's Pre-Intervention phase, and subsequent stages sync with the rest of my model where users engage in an iterative loop of collecting and reflecting on the intervention, leading to continued use or lapsing. My model expands on his concept by adding a step between *lapsing* and *resuming* with the arrows *deviate* and *guidance*. This emphasises the potential of technology design to re-engage users before they fully lapse. This highlights design strategies to re-engage users before they fully lapse, thus providing a roadmap for designers to sustain user engagement with self-care VR applications. My model focuses on providing a framework for designers to identify and address these deviations to prevent lapsing, while their model represents the reflection cycles of users that would happen within all phases of my model.

Technology-Mediated Reflection Model (TMRM). The Technology-Mediated Reflection Model (TMRM) [60] posits that users engage in continuous reflection, assessing how information of one's health data meets their needs in a cyclic process. In order for technology to facilitate reflection, it has to present the information in a way that matches users' expectations (conceptual cycle) and in a fitting timeframe (temporal cycle). Like Epstein's model [184], TMRM was crafted for personal informatics but resonates with the self-care journey my model addresses. It mirrors the iterative reflection process in my model, where users evaluate the alignment of features of self-care applications with their evolving needs over time, akin to TMRM's conceptual cycles. It underscores that as time progresses, users' perspectives and requirements may shift, affording designers to incorporate flexibility and adaptability to address users' changing needs over time. Central to the TMRM is the focus on technology that can mediate reflection processes. This mirrors one key aspect of my model, which emphasises that the design of technology can have the power to influence users' reflection and their decision to lapse or to continue using the application, by presenting its value.

The Longitudinal Goal Setting Model. The Longitudinal Goal Setting Model for Addressing Complex Personal Problems in Mental Health by Agapie et al. [3] represents a cyclical process of setting and adjusting goals through iterative reflection cycles. A single simplified goal is selected from multiple goals, which is adjusted to a single complex goal to then adjust the set of multiple goals again. Their and my model both emphasise the importance of reflection to achieve the desired outcomes, and have a health focus through simplifying goal-setting.

However, Agapie et al. [3] focus on supporting users in their self-improvement, whereas my model assists designers in sub-dividing complex goals to enhance application design. To that end, Agapie's model provides a starting point of how to achieve this: designers' singular complex goal (e.g. ensuring continued user engagement with an application), is divided into simplified manageable goals (e.g. transitioning users from the Pre- to the Begin-Intervention phase, from Begin to Core, and so forth). These get simplified even more (i.e. for the Pre-phase: I want users to choose my application, I want users to feel comfortable with my application, etc.). Thus, my model and the phase-specific guiding questions (compare Table 3.1), visualises already simplified goals, applying the Goal Setting Model for designers of SCTs and supporting them in achieving each sub-goal.

In contrast to those theories and models, my model contributes the outline of a user SCT journey combined with targeted design recommendations and design ideas that can support designers in guiding users through each specific phase. It overall promotes clear recommendations for ongoing user engagement and user well-being. It also paves the way for future research, inviting designers to test out different combinations of the proposed design ideas while also extending the list of possibilities due to their own research.

3.4 Unanswered Questions - Where to Next?

While my four-year PhD journey, encompassing more than six studies, provided substantial time to explore many facets related to the design space of VR-based self-care applications, it was not feasible to address every question. This section highlights the limitations of this dissertation as well as the most promising avenues for future research.

3.4.1 Limitations of this Dissertation

This dissertation constitutes a first step towards improving the variety and design of VR-based self-care applications for laypeople, yet, certain limitations have to be acknowledged. Thus, participant sampling, study design, data evaluation and generalisability of results are discussed in detail.

Participant Samples. The participant samples used in this research may not be fully representative. Despite efforts to acquire balanced samples in terms of gender, age, prior experience with VR, and cultural backgrounds, for example using online surveys and hybrid study setups spanning participants from over 15 countries to diversify the participant samples [448], the majority of participants were between 22 and 32 years of age, recruited from my own personal network and university environments. It remains an open question how different recruited samples might have affected the findings. Additionally, the sample sizes, ranging from 12 (*B - Haptics*) to 60 (*F - MoodShaper*) participants per study, still remain small to confidently validate all findings, albeit sufficient and in line with the average sample size of $N = 12$ for empirical research at CHI [102]. Recruiting based on snowballing and my own extended personal network is common practice in HCI [494]. The aim of this dissertation is to provide a multifaceted starting point for further inquiry and this approach allows for insightful findings. However, I still acknowledge that a uniform approach to participant sampling across studies, and across a more diverse population presents a valid approach for future research.

Study Design. Studies of this dissertation were of a cross-sectional nature and assessed the impact on users in a single instance. Longitudinal assessments, such as repeatedly testing the interventions, could have helped to discern the novelty factor of engaging in a still-considered “novel” medium for most participants and that could have influenced some of the findings. Further, field studies could have assessed ongoing engagement, continued use and the long-term impact on self-care behaviour change and mental well-being [473]. In self-care research, longitudinal studies help to explore how the SCT embeds into the everyday routine and its long-term impact on well-being. Measuring well-being often requires assessment over extended periods to accurately evaluate the effect, as it is a multidimensional construct involving hedonic and eudaimonic aspects, life satisfaction, income and more [485]. Thus, mental well-being is more of a trait than a state, explaining why the Oxford Happiness Questionnaire [248] used in *D - MoodWorlds* to measure well-being showed no significant impact after a single intervention. However, given the exploratory nature of this research, this thesis aimed to evaluate the one-time impact of self-care prototypes in a more controlled manner as a first step. Future studies should deploy VR applications inspired by the ones presented in this dissertation first to mental health professionals to further test risks, and then to laypeople and evaluate their effects over several months.

Evaluation. Further, most of the studies of this dissertation were based on an exploratory study design. In line with similar research in the field (e.g. [225, 440, 516]), this design was chosen to align with the research objectives focusing on providing in-situ support and exploring how VR can facilitate self-awareness and self-care. Further, the approach is novel and establishing a valid baseline with other VR applications is challenging, as my approach offers more than merely translating art therapeutic applications to VR (e.g. [237]), others do not focus on autonomous visual expression (compare [373]) or require technical skills from users which are not feasible for this dissertation's target group (e.g. [225]). Nonetheless, due to the explorative approach, I did not evaluate the effectiveness in comparison to more traditional approaches, such as face-to-face real-life therapy, and other established VR applications with similar aims. Future research should include comparative studies to assess and validate the effectiveness of the explorative evidence gathered in this dissertation.

Aligned with this limitation, data was analysed by myself, identifying as a female researcher in their late twenties, in combination with different research teams. Both myself and most co-authors have lived, received education, and worked predominantly in Central Europe, shaped by WEIRD (Western, Educated, Industrialised, Rich, and Democratic) backgrounds [563]. Our research expertise spans design, computer science, and psychology, with a focus on hedonic and eudaimonic well-being topics. This perspective has informed the structure and analysis of data across all publications. I acknowledge potential biases stemming from our cultural, academic, and personal backgrounds.

Generalisability. The objective of this thesis was to offer a set of insightful elements and design recommendations that can be considered puzzle pieces of safe and effective VR-based self-care design. My hope is that this thesis provides a more nuanced picture of the design space, which can be transferable to an extent to other VR applications and SCTs, without aiming to provide a perfect one-fits-all solution, in line with scholars emphasising that this aim is utopian and idealistic [86]. I hope that this dissertation provides the groundwork for the creation of more effective systems and inspires thought-provoking directions for future exploration.

However, I acknowledge that other methodologies, such as randomised trials, could have ensured that results generalise well across different settings [636]. Additionally, the applications tested within this dissertation are tailored to specific study setups and may not be directly transferable to consumer markets without further adjustment and testing for long-term use. For instance, while some procedures included the creation of a positive environment before beginning the actual self-care intervention, real-life applications might want to focus more directly on the interventions. Therefore, it is envisioned that any such application about to be published on consumer markets should be flexible, accommodating individual preferences and allowing users to customise the elements to suit their needs. Prototypes presented in this dissertation should not be published without further testing and the generalisability of findings should be considered with care.

3.4.2 Future Work

In the process of conducting this research, further exciting research endeavours have arisen, pointing a way to promising avenues for future work. One of the key concerns of self-care practice is to help people to understand their internal states. In that regard, this section points towards promising future work in regard to modality extension to facilitate introspection and scaffold self-care activities and to use (AI-driven) sensing and prediction of internal states through physiological data. Then, this section reflects on the possibilities of adapting the prototypes developed in this dissertation to various user groups, including neurodivergent people, different age groups and people facing mental health issues. The section ends by reflecting on what has to be done beyond the field of HCI to make VR-based self-care more prominent in public discourse.

Facilitating Introspection through Modality Extension. Comprehensive findings from this dissertation, in particular *Part III - Designing the Virtual Space*, underscore the potential of multisensory integration in VR, as sensory stimulation can potentially create positive affect, facilitate introspection and help to consolidate memories based on qualitative data from participants.

Engaging multiple senses in VR can significantly enhance immersion and impact [336]. However, most VR applications focus mainly on visual and auditory stimuli, with less research on haptics, thus restricting the sensory richness and potentially reducing the effectiveness of the experience [593]. Current VR hardware offers only basic haptic feedback, limiting its possibilities [350], and this dissertation has only explored the impact of passive haptic feedback on self-awareness. Investigating active feedback and tangible interfaces presents a valuable future research direction, inspired by works like those of Vaucelle et al. [592], who developed various systems for haptic therapy.

I further recommend exploring thermal, olfactory and gustatory implementation possibilities and their impact on self-awareness, autonomy and related concepts that are part of this dissertation. Thermal feedback was desired by participants of various studies to enhance relaxation and realism (B - Haptics), soothe them in their safe space (*D - MoodWorlds*, *F - MoodShaper*), and more vividly visualise happiness (*D - MoodWorlds*). Olfactory and gustatory elements could more effectively elicit memories, as particularly noted in *D - MoodWorlds*. As a starting point, I refer to works by Lyu et al. [336] for thermal, Maggioni et al. [341] for olfactory, Obrist et al. [407] for gustatory implementation possibilities for VR.

However, based on the importance of simplicity of visual environments and the procedure of self-care applications, I implore future work to carefully consider that too much detail and realism can reintroduce challenges associated with research conducted in actual environments [159, 391], as well as reduce the efficiency of self-care applications. More research is needed to investigate this balance.

Scaffolding Self-Reflection and Introspection through Modalities. This dissertation has focused on exploring verbal and visual scaffolding to guide users through their complex self-care tasks and to teach self-care strategies. However, scaffolding elements can also be used to provide feedback to users, for instance about their physiological health status. Leveraging different modalities with this aim could increase self-care activities such as self-reflection and lead to enhanced introspection.

As one example, in our research, *Light Me Up! Ambient Light Increases Heart Rate and Perceived Exertion during High-Intensity Virtual Reality Exergaming*, currently under review, we explored the use of real-time colour-adjusted ambient lighting in a VR exergame to visualise fitness and exercise levels. VR exergames offer gamified fitness activities in VR, and we investigated how to make them more effective and how to combine it with mental well-being. Thus, ambient light of the virtual space was used as qualitative means to promote self-reflection (similar to *C - VeatherReflect*), and as visual scaffolding (similar to *F - MoodShaper*).

This study tested the effects of red ambient light correlating with the player's heart rate on both physiological responses such as increased heart rate and perceived exertion, and psychological factors, such as emotional engagement, self-reflection, self-awareness and behaviour change. Our findings indicate that red ambient light not only intensified physical exertion but also influenced participants emotionally, ranging from discomfort to higher motivation. It could also pragmatically scaffold user behaviour, such as deciding to move a bit slower and breathing deeper to not over-exert oneself.

Overall, the exploration of feedback mechanisms and using different modalities for scaffolding options in VR is still in its infancy; there is vast potential in experimenting with various elements like colour variations, shapes, and movements of virtual objects for real-time feedback. Beyond visual cues, incorporating auditory or haptic feedback could also provide stimulating and engaging feedback, and could be investigated by future work. As inspiration, I recommend work demonstrating how to integrate physiological data with self-care to deliver personalised experiences that foster introspection and cognitive change [169, 522, 560].

Inferring and Predicting Internal States through Physiological Sensing. Understanding one's internal states and the status of one's mental well-being is a challenging task. While findings of this dissertation propose that the design of the virtual space, including passive haptic feedback and scaffolding elements, can facilitate aspects of introspection, many users would profit from more quantitative graspable data. Thus, on the diagnostic side, some of the main challenges that still remain are sensing mental states and predicting mental health outcomes, as well as mirroring this data back to the user [636].

Sensing physiological data and inferring real-time mental states are increasingly becoming popular with advancements in sensor accuracy, cost reduction and miniaturisation, for example through wearables such as smartwatches. Physiological data that can be linked with stress and with specific emotional states are brain waves, electroencephalogram (EEG) signals, electrocardiogram (ECG) patterns, galvanic skin response (GSR), heart rate (HR), heart rate variability (HRV), and skin temperature. However, accurately interpreting mental states from sensor data alone is challenging due to their subjective nature [565].

Thus, sensor data was recently paired with machine learning algorithms, large language models and artificial intelligence to enhance analysis [636]. Effectively, data collection is enhanced by input from smartphone usage and wearable sensors such as gyroscope, and users' text and speech input as well as images and videos that can be rated for mental state assessment. This multidimensional approach has the potential to identify mental well-being states with high accuracy, in some cases over 90% [636].

Yet, significant challenges remain when trying to sense and predict internal states. Most notably, there is a need for large, labelled datasets and a vast amount of time needed for machine learning training before being able to accurately assess individual mental well-being [636]. In order to provide personalised feedback, models need to be individually trained and tailored to ensure feedback is directly relevant and beneficial, which is time-consuming and, as of now, neither accurate nor possible with off-the-shelf devices [636]. This opens up the field for more research, in particular how to leverage VR's unique affordances to provide direct user feedback. Further, machine learning models currently still struggle with predicting future outcomes based on the data, especially in a personalised manner [56]. Overall, research into systems combining physiological sensing, machine learning and feedback mechanisms is sparse [636].

Overcoming these challenges requires more efficient data collection methods, improvements in predictive modelling and technical advances. Although sensing data has already been started to be integrated into VR experiences (e.g. [190]), these steps are essential before exploring how real-time assessment of internal states can be integrated into VR-based self-care applications to make them even more effective.

Adaptation for Various User Groups

The findings of this dissertation relate to adults who perceive themselves as mentally stable and healthy and who are not trained in psychotherapeutic strategies apart from a general interest in the matter of autonomous mental health and well-being management. Nonetheless, the findings should be adapted to the specific needs of different user groups, being particularly considerate when designing for vulnerable user groups. For instance, neurodivergent people, such as people with autism or ADHD, will need more customising options to accommodate their varied needs [171]. Research suggests that sensory stimuli such as sound or speed of elements in VR environments should be autonomously controllable [30]. The increase of distractors can have a negative impact on neurodivergent people [147], however, loud background noise was also found to improve the performance of some neurodiverse groups [147]. This indicates that design efforts should focus on customisation and personalisation. However, further research is necessary to investigate how the self-creation method is perceived and how scaffolding could be adjusted to meet the unique needs of neurodivergent users.

Further, the hardware of VR currently still excludes certain user groups. For example, the price although comparable to new smartphones still poses obstacles for low-income families. This issue is exacerbated by the general trend of rising mental health expenditures [411], making additional investments in VR technology a less attractive option for both individuals and healthcare providers. Further, VR controllers and the technical setup are usually tailored towards gamers, potentially alienating users with a lack of digital experience [432]. Although there have been advances to develop controller-free VR systems, users with physical disabilities such as tremors often find these inaccessible as well [171]. Additionally, people still face the problem of uncomfortable fit of the hardware. Thus, prolonged use can lead to physical discomfort, yet, this dissertation found that time is essential to internalise self-care strategies. This suggests a need for improvement in hardware design for inclusivity and to accommodate longer sessions [432].

Tailoring content to specific user demographics is also essential. Thus, the next sections point out promising future work in regard to specific age-groups and to people with mental health conditions.

Age-Group-Specific Needs. I encourage future research to adapt systems according to age-related needs. For instance, older adults might face distinct challenges, such as physical limitations like tremors [381] and varying degrees of digital literacy [636]. Thus, they might benefit from a personally-tailored approach to interacting within the virtual environment. Further, related works have shown that reflective capacity develops with age and also within an educationally stimulating environment [375]. However, the ability to reflect varies among individuals [375], and it should not be assumed that all older adults have enhanced reflective capacities, and some may moreover face cognitive challenges [171]. Thus, the optimal design for scaffolding for older adults is yet to be determined.

Further, technology should consider children and teenager's specific needs [63, 193]. It was found that these "digital natives" often prefer digital tools over face-to-face interactions [207], thus, VR-based SCT could serve as an effective tool to engage this user groups. However, their reflective capacity might not be as developed yet [375], which could indicate that more scaffolding could be needed to make self-care activities more effective for this user group, while emphasis should be placed on playful interaction at the same time to keep them engaged. Caution should be taken when exploring VR-based self-care for children, as children are more likely to become addicted to VR than adults and might lose a sense of their physical surroundings due to the highly engaging content [31].

Thus, as a first step, we explored the user group of teenagers. We conducted a study called *TeenWorlds: Supporting Emotional Expression for Teenagers with their Parents and Peers through a Multiplayer VR Application*, which is currently under review. In this work, we explore how VR could support teenagers' emotional expression and shared understanding in a multi-user context involving peers and parents. In a within-subject study (n=42), teenagers, together with either a peer or parent, used VR to visualise their emotions concerning a shared conflict, discussed them, and then collaborated on a joint drawing in VR. Thereby, they used a similar toolset as in paper *D - MoodWorlds*, *E - SelVReflect* and *F - MoodShaper*, but shared the physical space with their study partner. Our findings show that TeenWorlds helped mediate communication between teenagers and their parents and peers, which also fostered reflection and an appreciation for their interpersonal relationships. Our quantitative and qualitative findings show that TeenWorlds seems to work better when used with parents than with peers with respect to the experienced emotions, empathy with the interlocutor, and reflection. This indicates that, in order to achieve reflection, teenagers might require specific scaffolding, which was partly provided by their parents but, in many cases, was lacking when they were interacting with their peers. We discuss how future work could integrate this scaffolding, e.g. in the form of reflective prompts, and how systems like TeenWorlds could facilitate well-being, both by navigating conflicts and by connecting them with their parents through a joint activity that both parties enjoy. Nonetheless, while we found that teenagers require more hands-on scaffolding for complex emotional tasks, more research is needed that specifies the nature of this scaffolding.

Mental Health-Specific Needs. As was established early on in this dissertation, this dissertation targets mainly proactive self-care activities for mentally healthy and stable laypeople to improve their everyday well-being. However, in practice, proactive and reactive self-care can not be as easily established and that a high percentage of people will experience at least one episode of mental distress in their lives. Consequently, future work should explore how the approaches presented in this dissertation could be adapted for user groups with mental health conditions as well. Further, in the long run, my ambition is that insights from this dissertation might also inform systems that can be useful in clinical contexts to support participants in their mental health journey. This endeavour introduces additional complexities, particularly when involving vulnerable populations. Any system aimed at clinical application must undergo rigorous, longitudinal testing to secure clinical validation. It also necessitates a careful integration into various therapeutic methodologies, ensuring it complements traditional treatment approaches. Along similar lines, additional safety measures and guidance outside of the therapy sessions might be needed, which could be given by mental health experts or by very evolved technical systems, going beyond what AI can currently offer.

Drawing from prior research [540, 606], I hypothesise that a higher level of scaffolding might be beneficial for clinical mental health context and to provide additional safety mechanisms. However, this approach could potentially restrain users' autonomy. I propose step-by-step guidance paired with psycho-educational elements which inform the underlying psychological principles of each intervention, either by visual means or through voice-based guidance. Moreover, AI could fulfil the task of individualised scaffolding, discussed in greater detail in Section 3.4.2. The approach of using technology for careful scaffolding aims to balance the provision of necessary support without straining the mental health system and fostering individual exploration and growth within the therapeutic landscape using VR.

Significant concerns arise when considering VR for individuals experiencing acute severe mental health distress, such as experiencing a major depressive episode. While VR can serve as an adjunct to traditional therapy — potentially as a form of 'homework' to complement face-to-face sessions — reliance on such technology for these delicate topics is ill-advised without the inclusion of more adaptable, human-centric strategies. However, to date, the exploration of VR's applicability for diverse mental health contexts remains limited [28].

Adaptation for Groups Based on notions of social health, it would be interesting to investigate multi-person shared experiences. Inspired by research about interpersonal distance in VR [469, 597], it would be interesting to see how friends, in contrast to strangers, interact with each other when co-creating the virtual space. Further, it would be fascinating to discover if and how hearing and seeing others affect the user, especially regarding the perceived importance of creating something aesthetically pleasing, felt autonomy and feelings such as childlike excitement. An interesting user group in that regard could be couples, as they generally know each other very well but can also have conflicts with each other. Similar to *TeenWorlds: Supporting Emotional Expression for Teenagers with their Parents and Peers through a Multiplayer VR Application*, a multi-user setup with couples could reveal user-group specific needs and generate design ideas that could facilitate relatedness and connectedness, improve interpersonal communication and help to solve conflicts.

3.4.3 Towards Public Acceptance of VR-based SCT

Thus far, this section has highlighted promising directions for future work in the field of HCI. Yet, there is another area close to my heart: the broader public acceptance of VR-based technologies for mental health and well-being. Beyond specific HCI research, future studies could investigate strategies to reshape public perceptions, positioning VR as a widely accepted self-care tool for enhancing mental well-being.

To achieve this, the content of consumer-market VR applications must first evolve to reflect this new focus. The predominant focus is on gaming rather than therapeutic applications on consumer markets [62, 557]. This focus strengthens the societal perception of VR as primarily an entertainment tool, diminishing its legitimacy as a mental health intervention [432]. Even healthcare providers seem to not support VR enough in that regard, as can be exemplified by the decision of insurance companies not to cover video game-based mental health interventions [40]. In regard to content on consumer markets, own research (*A - AppSurvey*) has emphasised and re-validated prior findings (e.g. [339]) that currently there are insufficient regulations as to what accounts as a "wellness application" to use a term from the filtering mechanism of the gaming platform Steam. A good example in this context might be the German system of "prescription applications", also known as DiGa's (digital health applications), which have been rigorously tested by experts and are made available online by the German state [202]. To mitigate risks of users encountering (un-)intended harmful design, policymakers should intervene to establish clear regulations, enhancing trust in the labelling system in users.

Moreover, the public often regards clinical treatment approaches as benchmarks, serving as role models for state-of-the-art methods both for mental health and for mental well-being care [636]. However, VR is seldom utilised in therapeutic contexts [636]. In 2019, only 17% of licensed psychologists were trained to use VR, and of those, 62% use VR for exposure therapy and only about 38% promote VR-based autonomous self-care [196]. As the healthcare system is slow to adapt to modern technology [429], and comprehensive clinical trials are lacking [636], it is not surprising that it creates scepticism regarding their effectiveness in public discourse. Cycling back to one of the current key design challenges (see Section 3.1.2), future work should find possibilities to highlight the technology's potential to complement, rather than replace, professional mental health support, educating therapists to increase their digital literacy and be in open discourse with them about benefits and risks, for instance by involving them in the design process.

These challenges underscore a cyclical dilemma: the prevailing association of VR with gaming is continuously reinforced, combined with the non-acceptance of VR in therapeautic practice, which in turn influence public discourse. As a result, there is little demand for diversification of content in the VR consumer market. Addressing these barriers should receive concentrated effort from the research community. Besides necessary advances on the technical side of VR system developments, aiming to reduce costs, and improve design inclusivity and physical comfort, I also advocate that researchers should extend their influence beyond academia, engaging with policymakers, healthcare professionals, and the broader public to reshape societal perceptions of VR. This involves promoting the integration of VR into general mental health care, initiating the development and validation of VR applications through rigorous clinical trials, and generally publishing well-designed engaging self-care applications on consumer markets to diversify the landscape for the wider public. This proactive approach is essential for changing societal perceptions and fostering the acceptance of VR as a valuable tool in mental health and well-being treatment.

4 Conclusion

As more individuals seek to manage their mental well-being autonomously, Virtual Reality (VR) shows great promise as a Self-Care Technology (SCT). It provides immersive and customisable environments that can not only facilitate self-care activities but can also be designed to enhance their effectiveness and improve overall mental well-being. To explore the design of engaging and meaningful VR-based self-care activities, this dissertation employs a comprehensive methodological approach, including an application survey and five empirically evaluated prototypes for different self-care activities.

Drawing on the comprehensive findings of all studies, this work presents four key contributions: (i) Empirical analyses highlight how VR's unique affordances, such as enabling introspection through solitude in personally meaningful spaces, present a promising approach to self-care. (ii) Incorporating autonomy as a foundational motivator, such as through the self-creation of virtual environments, was found to be key to making self-care more relevant and effective for people without prior self-care knowledge. (iii) Four specific design recommendations for VR-based self-care applications. They emphasise that the ideal virtual environment — ranging from realistic and modality-enhanced to abstract and minimalistic — only exists in relation to the individual's needs and self-care objectives. Consequently, VR-based self-care applications that are perceived as meaningful and are designed for impact both before and after the intervention can enhance the effectiveness of self-care practice. To achieve this, they could be designed for both inter- and intra-personal adaptability, for instance, by empowering users to create their own virtual spaces. However, this open-ended, playful approach should be balanced with structured scaffolding elements to counterbalance the valence of experiences, optimising the effectiveness of self-care activities. (iv) Finally, this thesis presents a process model that helps designers create effective self-care technologies by offering phase-specifc design ideas, promising to enhance sustained user engagement with the applications.

I hope this work, by contributing a systematic understanding and specific recommendations, inspires the development of VR-based SCTs that tailor virtual spaces to individual needs and thus create mental spaces dedicated to caring for one's everyday mental well-being.

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