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Work-in-Progress–Potentials in the Immersion Experience of Schoolchildren in Virtual Reality: The Importance of Sensory Integration regarding the Immersion Effect

Monika Fuchs-Brantl

Pedagogue at Hospital School Vienna, MEd-Candidate at University College of Teacher Education Lower Austria
monika.fuchs-brantl@schule.wien.gv.at

Abstract. Sensory integration (SI) "refers to a process of perceptual processing in which sensory impressions are organized and processed by the brain." [1] SI plays a central role in both perceptual processing of real-world stimuli and understanding of how virtual reality (VR) tricks the senses. Because SI relies on the basic senses of the vestibular, tactile, and proprioceptive systems, it is thus closely linked with immersive virtual reality (iVR), and it's potential applications [2]. This results in opportunities, - for example, considering the basic body senses could help mitigate some of iVR's negative side effects, such as disorientation. However, it also brings challenges, especially for iVR-use in children, whose ability to distinguish between physical- and virtual reality is not yet fully developed. This so-called transitional competence develops from high-quality (that is, real-world stimuli) body sensory perception and its subsequent SI. However, on the specifics of these processes fundamental research is lacking. Thus, relevant open questions are discussed in this work-in-progress-paper, specifically, a) how are sensory functions related to body self-image, b) how does sensory experience affect identity development in school children, and c) what potential does the immersion experience offer for the use of iVR in school children? Considering development-age when using iVR with schoolchildren would enable appropriate, safe application of this technology.

Keywords: Sensory Integration, Virtual Reality, Immersion.

1 Introduction

A market analysis from 2023 predicts that the market for immersive technologies will quadruple by 2028 [3]. It is therefore foreseeable that immersive technologies will also be increasingly used in education in the future. "Immersion is the term used to describe immersion in a virtual environment." [4] It is defined as "the degree which the range of sensory channel is engaged by the virtual simulation." [5] VR goggles create a very high degree of immersion. "Virtual reality (VR) is a computer-generated reality with images (3D) and in many cases also sound." [6]. Presence in this context is the subjective aspect of this experience and "defined as one's sense of being in the virtual world." [7] This work refers to VR that creates a complete iVR through VR headsets. The immersive experience can be both - enriching and disturbing [6]. It brings both - opportunities and challenges. "During its duration, normal reality ... is pushed back, and it can be difficult and costly to return to it and find one's way around it again ..." [6] If public educational institutions aspire to create a future-oriented education that is linked to humanism, it seems essential to address immersive media and their potential opportunities and risks. An article on remote work points out that immersive media are associated with increased effort for people compared to video conferencing. This is linked to the sensory and cognitive stress associated with the immersion effect [8]. The immersion effect is associated with a disembodiment - "to divest of a body, of corporeal existence, or of reality" [9] - in which one is transported out of one's own body perception and into the virtual environment. The sixth sense, commonly referred to as the body sense, plays an important role in this context - both for understanding the immersive effect and for the necessary adaptation of the perceptual system [2]. The current state of research it is customary to briefly exemplify some of these positive potentials of iVR for the education sector [10–15]. Remote learning settings, but also specific VR applications, can create special opportunities for physically or neurodiverse impaired children [16–24]. IVR is already employed in concentration training and attention deficit disorder therapy, and could generally facilitate and expand therapy accessibility [25]. However, bridging the gap between immersion and presence is also a challenge for the human perceptual system, which is based on the integration of sensory impressions [2, 26]. SI plays an important role in returning from an immersive experience back to physical reality to restore a sensory order adapted to physical reality after the sensory illusion underlying the immersive-virtual experience [27–31]. Due to their still developing - and therefore fragile - sensory system, children are often not yet able to distinguish reliably between physical and virtual reality [32]. This makes it even more urgent to develop comprehensive expertise for children's interaction with immersive media. Without an understanding of the links between SI's role in child development and the perceptual disruptions in iVR, the safe use of iVR in school-age children is questionable. No study has yet been found to address this question.

2 Theoretical Foundations

In the concept of SI, the basic senses are understood as organizing instances of human perception on which body orientation and movement planning are based [26]. Physical reactions such as headaches, dizziness, or nausea during iVR use indicate sensory overload due to the immersion effect [33, 34]. Related to this is the symptomatology referred to in this context as cybersickness (CS), which occurs when the eyes' perceptions diverge from the perceptions of the balance system in the inner ear [33, 34]. The vestibulo-ocular brainstem reflex supports a stable visual perception. It requires about 30 minutes time to regain its normal function after 20 minutes of iVR application. This regeneration phase also serves to readapt spatial vision and is associated with an increased risk of accidents [35]. The vestibular system is thus linked to immersion tolerance, motor action planning and cognitive performance [36]. Sensory perceptions are sometimes compared to brain food, which cannot be digested by the brain without well-organized sensorimotor processing [37]. Diffuse or contradictory perceptions can thus lead to moments of danger. Well-trained body awareness, on the other hand, enables better flexibility in SI [38, 39]. Body imagery and balance functions can be improved through SI therapy [40]. Perception of the environment and body awareness are closely related; body imagery affects learning ability, attention, intellectual performance and emotional well-being [41]. There are still many unanswered questions about the function of the mental system; in any case, information can enter the brain even without conscious perception [42]. This is referred to as subliminal messages and the associated risk of unconsciously influencing behavior [43]. According to the theory of predictive coding, our brain processes sensory impressions based on its internal model of the environment [29]. The prefrontal cortex, the frontal region of the cerebrum, is thought to play an important role in this. It develops slowly into young adulthood and is supported by physical activity [44]. Compared to adults, children of developmental age cannot sufficiently modulate the changes in the brain caused by the immersive presence experience in iVR - they are detectable by EEG [45–48]. The prefrontal cortex houses working memory, impulse control and mental flexibility and is shaped by creativity, memories, and social interactions [49, 50]. Attention itself is considered a signal amplifier, and the optimal focus due to the immersion effect speaks in favor of iVR training for ADHD, although balance problems occur more frequently in these children [51]. Its application in the field of neurodiversity seems interesting and promising for the future, as the pressure of suffering in everyday school life is great for everyone involved due attention problems [25]. Through iVR, emotional reactions are evoked as if one were confronted with reality [33]. This is where storytelling for empathy training comes in, as used in, for example, the Upstander application on the topic of cyber-bullying by VR for Good by Meta [52]. The safe use of such perfectly sensible VR apps by educational institutions, however, requires ethical embedding and clear application guidelines [11, 53–56]. The application notes produced by Meta, for example, do not contain any references to correlations between VR-use and SI [57]. Since psychological development in children between six and twelve years centers around building self-confidence, social cooperation and teamwork, aside from acquiring cultural skills, great care must be taken when navigating virtual environments [58]. During these sensitive phases of childhood development, the central nervous system is particularly susceptible to external influence [59, 60]. Here, it is important children should feel in control of their own body during the identity-finding process; sensory and motor skills are closely linked - and this so-called psychomotor circle is the foundation of self-efficacy and resonance experiences [61]. Digitality in general, and operating aids employed in inclusion particularly, provide additional opportunities for children's resonance experiences and participation [62, 63]. Responsive experiences are nevertheless primarily based on real-world experiences - "learning by doing is better than a virtual simulation, even at school." [64] Children's quality of life requires sensory experiences as the foundation for a healthy relationship with the world [32]. In this respect, the digital world merely offers an "as-if resonance space."[64]. Through virtual worlds, a part of the person is drawn into them through their attention focus, but the body remains connected to the embodied reality. This leads to a split in people's areas of experience. An incongruence of sensory impressions can disrupt self-perception and self-awareness, which is based on a good connection between body and mind, and so may lead to false memories, depersonalization, and dissociation, especially in children under the age of ten [32, 65]. As children have not yet developed sensory integrity, and must combine sensory experiences with their motor skills, digital media potentially introduce fragility during developmental age. This is precisely where and why teachers are responsible for dealing competently with immersive media. For a basic awareness of media, it is necessary to fully recognize the real world on the one hand and to be familiar with virtual spaces on the other [64]. In its predictive embedding of perception, it refers to an individual's previous experience of physical reality and influences the personal sense of immersion [66–68]. A description of the immersion criteria and assessment parameters regarding iVR content could help select appropriate VR applications for children. More research is needed on SI, and SI should inform iVR-use recommendations, as the relevance of individually integrating the basic senses is known to affect 1st person-mode compatibility in VR [69]. Torso stability is also related to the basic senses, primarily to proprioception, and can improve VR tolerance [70]. However, the degree of perceived immersion is not only determined by the individual, but also depends on external factors, the description of which could usefully supplement application notes to better assess and classify VR apps.

3 Current State of Research

About 10 years ago, several studies were carried out by the Brain Initiative founded under the-president Obama - including on the rubber hand illusion [71–73]. "The rubber hand illusion... is a sensory illusion... A test subject places their right hand on a table, and the scientists cover this hand and place an artificial hand next to it, which appears real. They then stroke both the covered real hand and the visible fake hand with a brush ... after a short time, the test subjects have the feeling that the artificial hand is part of their body. This is explained by the brain trying to process the contradictions between the different sensory impressions ..." [74] The widespread availability and affordability of Meta's Quest II VR goggles as the first stand-alone device (i.e., without a cable connection between controller and headset) renewed the interest and research in the field of neuroscience and the rubber hand illusion [75]. Studies demonstrated that school-age children, between age six to around 13 years, may experience confusion and inadequate differentiation between real and virtual social beings, and consequently basic developmental skills may be disrupted [55, 65, 76–78]. While initial iVR application trials with children did not show any major problems, the biological and technical elements of iVR applications are not yet sufficiently understood in terms of their complexity and interdependence [79, 80]. Extensive information materials are available on iVR, but there is hardly any knowledge about body sensory development and iVR-use aspects in school children [81, 82]. Children require special protection during their development to be able to deal with their environment and position themselves within it [60]. Sensory perception of physical reality, in turn, forms the basis for processing virtuality. Perception is subject to many influences; for example, body perception and the reciprocity of body and mind are important for SI [83, 84]. Learning spaces can be expanded through iVR [85]. In addition to activating physically impaired people, IVR training can improve motor learning as well as SI, gross and fine motor coordination (tremor and dyskinesia) and psychomotor functions [86–91]. However, long-term effects have not yet been confirmed and negative effects cannot be ruled out [92–95]. Reality is defined individually, is developmentally dependent and the brain has a weakness in distinguishing between physical and virtual reality [84, 96]. The connection between sensory processing and immersion effects offers both opportunities and challenges. In principle, perception can be largely manipulated [75]. A body's own perception, caused by its own movement, is necessary to orientate oneself, to form or confirm one's own identity - without it, an important reference point for the sense of self is lost [97–99]. Multisensory stimulation has an impact on self-confidence and body self-image [100]. Because the loss of reality, due to the immersion effect with the accompanying cortically measurable disembodiment, is a challenge for the developing brain, clear rules of iVR application are needed [44–48, 50, 101, 102]. Perception is personally predictively coded and requires an individualized use of iVR that considers the fragility moments of developmental age [103]. In addition to media skills, proactive engagement with technological change requires self-competence based on sensory experiences and qualitative body- and movement perception pre-experiences [104, 105]. IVR is considered to have future potential for the school setting [106]. On the one hand, organizational support is needed, and on the other hand, competent teachers are required for the healthy use of iVR [85, 107–109]. High-quality iVR content with good interaction options offers opportunities for participation and physical self-efficacy experiences for people who, due to physical limitations, are unable to experience some spaces in the physical environment [110, 111]. These opportunities should be safe to use for children and young people, particularly those with special physical needs. This gives rise to an interest in investigating the following research question and surveying the current state of research.

4 Description of the Study, Research Question, Hypothesis, Design

The central research question is: What role does sensory integration (SI) play in the immersion experience when using virtual reality with school children?

With the following detailed questions:

1. How are sensory functions related to body self-image?
2. How do sensory experiences influence the development of identity in schoolchildren?
3. What opportunities and challenges of the immersion experience can be identified for the use of VR-use with schoolchildren?

Both development and risk potentials shall be identified and named by interviewed experts. Research questions 1 and 2 are addressed by means of literature analysis and current research surveys. Both of these show, with regard to question 1, that an impaired vestibular system may result in dizziness, and is often accompanied by an out-of-the-body-experience that may correlate with neurological or psychological factors, e.g. depersonalization [112]. Well-established body awareness allows for greater flexibility in SI [38, 39]. The more synchronous the visuo-tactile and the visuo-vestibular correlations, the better one's body perception, with the visuo-tactile correlation being dominant [113]. Irritations of the sensory control circuits may lead to the so-called rubber hand illusion, that is, the sensory incorporation of a rubber hand into one's own body representation [114]; this illustrates the relativity of body perception [115]. The less clear the internalization of one's own body-image, the stronger is the rubber-hand illusion [116]. Here, body-representations in body-illusion experiments influence one's range of perception [31]. According to Frostig [41], a distorted body image, which encompasses all body-related sensations, can be attributed to a faulty classification of kinesthetic (that is, originating from the muscles) or tactile (that is, originating from the skin) stimuli [36, 117]. Visuo-tactile, cardio-visual and vestibular stimulations as well as the inner, visceral signals have a general effect on body self-image, SI, cognitive stimulus selection, and the perception of touch, pain and self, that is independent of the individual perception profile [101, 118–123]. Full-body illusion and iVR experience affect body self-image and physiological responses such as body temperature, brain waves, and heart rate [123, 124]. How the orientation in the 1st person mode is tolerated, depends on individual integration of the basic senses [69]. Referring to question 2 Ntoumanis and Tsakiris explain, that sensorimotor capacities strongly influence our learning and perception abilities, our body-identity and our environmental interaction [125, 126]. Proprioception forms the base of body- and movement image, muscle tone and positioning in space, and is directly linked to the tactile and vestibular systems. Furthermore, embodiment is a complex, individual and predictive, sensorimotor process of differentiation of self from environment and serves in identity formation [127–130]. During concrete-operational development, real-world environmental experiences are thus essential for the formation of a child's identity and constructive learning processes, and should be accompanied by movement [99, 131, 132]. Through such full-body, simultaneous environmental interaction, the body sensory system can promote the ego-perception of the self [133]. Immersive VR acts on the self-concept [30, 31], and there is clear scope for manipulating humans through visually created reality [134]. Self-identification is related to body self-awareness, which is explained by both functions being connected to the same neurobiological cognition areas in the brain; identification with a virtual body is detectable in the cortex [102, 135]. Neurological and psychiatric studies on illusory self-perception of the body point to connections between body sensory processing and self-awareness or identity [136, 137]. Misconceptions of the physical environment may arise, when movement and physical events in the virtual world are not experienced in a meaningful context [138]. Special caution is advised when using virtual environments with six- to twelve-year-old children: here, the focus of psychological development lies on increasing self-confidence in the context of social collaboration and teamwork, as well as acquiring cultural techniques [58].

The deductively identified criteria for the immersion level as a compatibility indicator of iVR applications form the basis for the creation of the interview guidelines referring to question 3. Individually guided interviews, with eleven experts, were conducted as an interview study during November 2023 to January 2024 [139]. Additionally, several iVR-user interviews were conducted at the Haus der Wildnis / Lunz am See – Austria with interviews following the Critical Incident Technique and intended to identify the personal application highlights in the positive as well as negative user-experiences [140]. The critical incidents were also asked of the experts.

The selection of interview partners is not representative in the quantitative sense but is based on representativeness of content in the qualitative sense [141]. Expert interviewees' selection was based on in-depth research in the field and existing contacts. Interview-evaluations will be carried out deductively in the first step [141]. In the second step, the results of the interviews will be used to inductively create further subcategories for the three main categories (see Fig. 1), which are intended to clearly summarize the opportunities and challenges of the connections between sensory integration and the immersion experience. This might also result in a sharpening of the subcategories regarding the sensory development-age of schoolchildren. These findings will provide the prerequisites for identifying application criteria for iVR-use in schoolchildren.

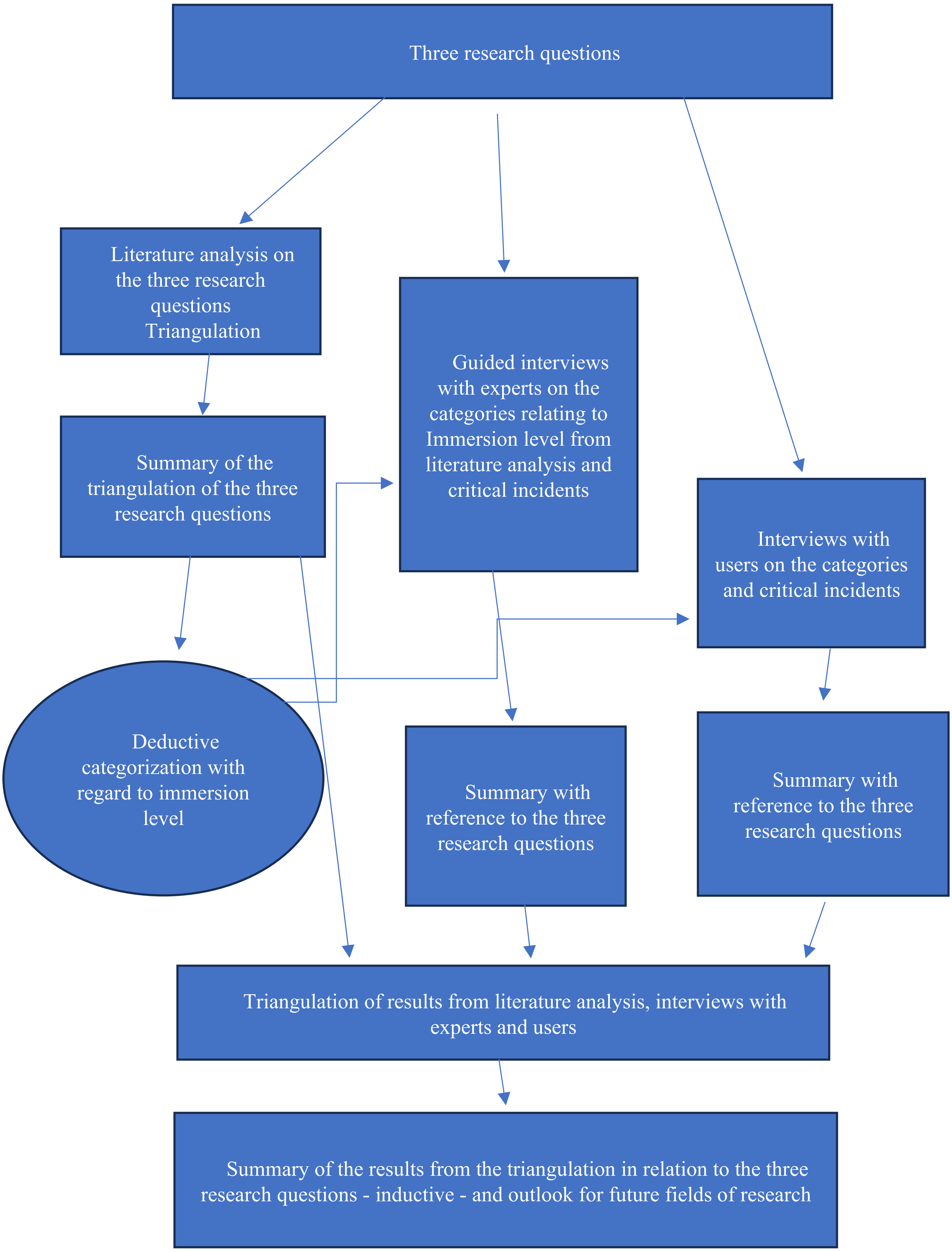

Fig. 1. Graphical representation of the research design.

5 Individual Schedule

Creation of the interview concept at the beginning of December 2023, Conducting the interviews by January 2024, Evaluation of the interviews by May 2024, Summary of theory, current state of research and study results by September 2024.

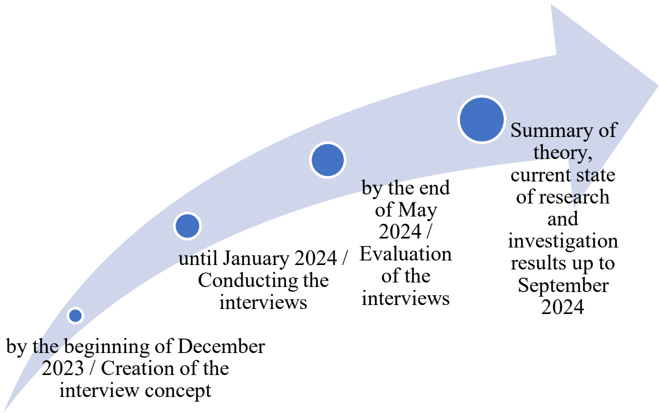

Fig. 2. Individual schedule.

6 Interview Guidelines

General questions for all expert interviews: From the literature analysis, criteria on the immersion level and the dos and don'ts to be queried crystallize - on the user experience and on critical incidents that indicate particularly noteworthy points. Open final question: Additional information from the personal field of work on opportunities and challenges, space for aspects of the topic that have not yet been considered.

Interview partners:

Some of the interview partners were known from online events such as VREduNet, XR Vienna, XR Bavaria and Boston VR. They also provided additional recommendations for interview partners from the Tech4Good movement. Further recommendations resulted from personal visits to the exhibitions in the House of Wilderness and the House of Digitalization.

List of interview partners: developer of XR solutions – Austria, developer of VR for brain sport and ADHD therapy - Germany, psychologist and motion sickness researcher - Canada, developer of XR-solutions in the education sector – Czech Republic, researcher at Chair of Human-Computer Interaction – Germany, supervisor of the FabLab of the Province of Lower Austria in the House of Digitalization - Austria, Employee in the exhibition department of the House of Wilderness - Austria, consultant for VR in education - Ireland, founder of The Gatherverse - a global ecosystem to discuss ethics within emerging technologies - Silicon Valley / U.S, founder of the Child Safety Initiative XRSI – Italy.

User survey at the exhibition Haus der Wildnis/Lunz-Austria: survey of families on site - questionnaire (Forms survey tool) for over 13-year-olds using QR codes for mobile devices. The age group from 5 to 13 years is interviewed in person in the presence of a parent/guardian or trusted adult (e.g. grandparent).

The user survey on critical incidents was conducted in person, while the expert interviews took place online via Teams-Meeting. The transcription software integrated in Teams was used. The transcripts were edited manually, and the individually defined transcription rules based on Mayring [142] were applied to improve readability.

The interview guide for the guideline-based expert interviews consists of seven questions based on the roughly deductive categories, and one open question that can lead to further inductively determined categories. Both, the guided interviews and the forms survey will be analyzed using a mixed-method approach with the help of Mayring's qualitative content analysis [142]. The MaxQDR software will be used for the analysis. The available text material will be broken down into small parts systematically and assigned to the categories formed from the theory or the category system developed on the material. This will be provided with coding rules and anchor examples. In the current research process, the transcripts are in the final clearing phase.

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