MRnews: Design Explorations into Accessibility and News

Fay Pedersen Tveranger

Master's Thesis of Media and Interaction Design
Department of Information Science and Media Studies
University of Bergen

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Abstract

Creating accessible technology and content is generally seen as beneficial for all users. This is particularly important when the content has a significant societal impact, such as news stories. To find new and innovative ways to engage users, digital news outlets are faced with challenges related to accessibility. In the case of Mixed Reality (MR) technology, the increasing interest emphasizes the need for the technology to be inclusive and accessible. The embodied nature and affordances of MR technology enable users to manipulate virtual objects using real-world knowledge and in real-time and enable them to utilize a wide range of skills when interacting with such systems. In turn, leveraging these affordances can enhance the accessibility of the task at hand. Contributions to developing accessibility guidelines have been made, and the use of MR applications to enhance accessibility is on the rise. However, these contributions are most prominent in education and not for leisurely use. This research project investigates the affordances of MR and of the Augmented Reality (AR) Head Mounted Display (HMD), HoloLens 2 (HL2) in particular, and how these can be leveraged to enhance accessibility when reading digital news.

This is a Research through Design (RtD) project carried out in participation with users by conducting design activities and user evaluations. The RtD-process is supported by prototypes developed through an iterative process. *MRnews* is an application built for Microsoft's AR HMD, the HL2. The implemented design showcases how news content creators and developers can leverage the affordances of MR technology to achieve accessibility in news stories. The results point toward direct manipulation of virtual content utilizing the spatial nature of MR technology and the use of sensory cues to keep the user oriented and focused impact accessibility.

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1 Introduction

Providing accessible technological solutions that accommodate various users' needs, notably for people with disabilities, is generally seen as beneficial for all users (*The EIDD Stockholm Declaration 2004*; Hedvall, 2009). However, legislation and implementations of accessibility guidelines are often slow compared to technological innovation (Inal et al., 2020). The digital news space encounters difficulties when it comes to the intersection between compelling storytelling and being accessible to all users. Engaging the public in the on-goings of the world is essential for a democratic society (Picone, 2007). In digital news and digital written texts in general, sensory cues that help readers focus and stay oriented are often omitted, which notably impacts people with dyslexia (Cavalli et al., 2019; Mangen et al., 2019; Watson & Wallace, 2021). In the case of the not entirely new but increasingly popular computer interface of Mixed Reality (MR), there are opportunities to develop guidelines for accessibility before widespread adoption. MR is an umbrella term that covers a range of systems that mix virtual content with the physical world (Azuma, 1997; Azuma et al., 2001).

The rapidly growing interest and range of use cases for the technology, in turn, emphasize the necessity to map out and cater to the needs of the various users. Efforts have been made to provide guidelines for developing accessible MR applications (Elor & Ward, 2021; O'Connor et al., 2021; Vi et al., 2019). There are several contributions developed that leverage the affordances provided by MR systems to increase engagement in learning (Birchfield et al., 2009; John et al., 2022; Lindgren et al., 2016; Zhang et al., 2023), in medicine and psychology (De Witte et al., 2020; Flobak et al., 2019), to impact workflow (Ellenberg et al., 2023; Manuel et al., 2021), and for the purpose of enhancing accessibility (Barbosa et al., 2019; Ellenberg et al., 2023; Stearns et al., 2018). The contributions cited are primarily situated in learning environments, such as schools, museums, and industrial environments, and do not involve leisurely day-to-day activities, such as reading the news. The affordances of MR technology are its ability to provide users with contextualized representations of virtual objects that can be manipulated directly and in real-time (Johnson-Glenberg, 2018; Zhang et al., 2023). To investigate the affordances provided by a specific MR technology, such as the HoloLens 2 (HL2), it is necessary to understand what it entails to interact directly through one's body. A phenomenological approach was utilized for added perspectives on this, particularly Dourish's account of *embodied interaction and embodied technologies*. Phenomenology and embodiment outline the foundations for other central concepts of this thesis, such as *affordance* and *accessibility*. The notion of affordances in this thesis is based on the affordances of J.J. Gibson (1979) and the utilization of the term to inform design by Gaver (1991). Their notion of affordances and the application of it in the field of HCI will be discussed later.

This research project aims to investigate the affordances of a specific MR technology and how to build upon this knowledge to enhance the accessibility of digital news articles presented in MR environments. In combining the theoretical frameworks of affordance and embodiment and knowledge about accessible digital written text and MR systems and applications, the following research question is addressed:

In which ways can the affordances provided by wearable MR technology enhance the accessibility of digital news articles?

Working with domain experts, IT professionals, and end-users, several prototypes were developed throughout four iterations of employing *Research Through Design* (RtD). The RTD approach was combined with Participatory Design (PD) to better account for the relationship between the different stakeholders: *media outlets*, *users* and *users with disabilities*, complex technology: *HL2*, and the societal significance news maintains in our society as *the public watchdog*. For this project, *Norsk Rikskringkasting (*NRK) and *Dysleksi Norge* were involved in the early stages of the project. NRK aided in defining a problem space and outlining challenges people encounter when reading digital news. People involved in Dysleksi Norge aided in providing invaluable information about the diagnosis through personal anecdotes as well as official guidelines and legislation connected to accessibility.

Based on the data gathered throughout the iterations of the RtD process, some contributions to the field of accessible MR applications have been made:

1. An outline of affordances provided by MR technology, notably the HL2, that aid in enhancing accessibility in news articles…
2. ...showcased in the prototype *MRnews*, that leverages these affordances to successfully present an article in a MR environment.

The following chapter outlines the background and theoretical frameworks central to this research project. The research method and an overview of the data collection process are presented in Chapter 3. Chapter 4 offers an in-depth account of the RtD-process. This chapter is structured after the RtD life-cycle depicted in Figure 5 and embodies the iterative nature of design research. Chapter 5 discusses the research's findings, Chapter 6 deals with challenges and limitations, and future recommendations, and the conclusion is provided in Chapter 7.

2 Background

In this research project, two central theoretical concepts for enhancing accessibility in MR applications are *embodied interaction* and *affordances*. In this research project, Embodied interaction is an entryway to understanding the impact of directly manipulating objects with one's own body in MR environments. To understand these concepts in relation to MR technology and where they originated from, it is appropriate to utilize Paul Dourish's account of them. This is deeply tied to his perception of the world, or rather, which understanding the world *affords* us. To illustrate the evolution of human interaction with computers, he goes through the history of interaction, which encompasses the concepts of *tangible* and *social computation*. His main argument is that the common denominator between *tangible* and *social computation* is based on phenomenological understanding and that they are notions of embodiment. This argument will be briefly outlined by presenting ideas connected to embodiment and the creation of meaning from phenomenological thinkers such as Heidegger and Merlau-Ponty. The concepts mentioned above draw from various fields, such as psychology, sociology, anthropology, and philosophy, and are all recognized in HCI. Building on the understanding of embodied interaction and affordances, a brief definition of Mixed Reality (MR) is provided. Lastly, accessibility and accessibility involving MR systems and use cases are discussed.

2.1 Phenomenology and Embodiment

According to Dourish (2001), phenomenologist thinkers study the connection between embodied action and meaning, where the world is already filled with meaning, and the meaning is found in how the world is available for our interactions. Phenomenologists argue that perception starts with what is experienced – they want to "see and understand" rather than to "understand and see" (Dourish, 2001). In contrast to phenomenologist understanding, Cartesian dualism makes a strong separation between the mind and the body, and that perception starts with an abstract understanding of a phenomenon (Dourish, 2001). This view of perception has been argued against because of its decontextualized approach to the world (Gaver, 1991), and furthermore, a disembodied mind would not have the opportunity to act in the world (Dourish, 2001).

Heidegger, a phenomenologist who has put his mark on HCI, also rejects the notion of a separate mind and body. Instead of asking, "How can we know about the world" Heidegger asks, "How does the world reveal itself to us through our encounters with it?" (Dourish, 2001, p. 107). The French phenomenological thinker Maurice Merleu-Pointy gives the body and embodiment a central role in his work (Dourish, 2001). Dourish points to three different understandings of Merleu-Ponty's embodiment: the physical embodiment of the human being (its size, shape, etc.); second, the skills one has developed; and third, the cultural understandings gained from the world we are embedded in. Dourish uses a phenomenological foundation to discuss embodied interaction, a paradigm for interacting with digital technology (Svanæs, 2013). Dourish's use of the term embodied interaction involves "[…] the creation, manipulation, and sharing of meaning through engaged interaction with artifacts" (Dourish, 2001, p. 126) and that "[…] embodied technologies participate in the world they represent" (Dourish, 2001, p. 183). Furthermore, he does not only imply physical embodiment but also social phenomena. Interactions are embodied in the sense that how they are situated gives them meaning and value (Dourish, 1999).

2.2 Affordances

Dourish points to the work of psychologist J. J. Gibson as someone who also draws attention to physical embodiment as a central aspect of how we interact with the world. The term *affordance* was coined by Gibson, who developed *ecological psychology* (Dourish, 2001; Gaver, 1991). Furthermore, ecological psychology was developed as an alternative to the cognitive approach that followed Cartesian dualism (Gaver, 1991). In ecological psychology, affordances describe the features a physical environment provides animals (Gibson, 1979). The description of the concept has later been specified, and Dourish offers this account: "[…] an affordance is a property of the environment that affords action to appropriately equipped organisms" (Dourish, 2001, p. 118). Gibson's affordances have since been extended to encompass IT systems (Steffen et al., 2019). Discussions about Gibson's affordances have significantly impacted the development of the concept of affordances and HCI as a field (Dourish, 2001; Kaptelinin & Nardi, 2012).

Donald Norman and William Gaver are prominent names in design and HCI that utilized Gibson's concept of affordances. Norman is perhaps best known for his sentiment that good design suggests how a device should be used (Dourish, 2001) and apply this sentiment to everyday artifacts such as door handles (Gaver, 1991). Gaver utilizes the concept of affordances to inform design decisions of interactive artifacts and as a tool for user-centered analyses of technologies (Gaver, 1991). Gaver (1991) says this about affordances: "Affordances are properties of the world that are compatible with and relevant for people's interactions. When affordances are perceptible, they offer a direct link between perception and action; hidden and false affordances lead to mistakes". Gaver (1991) argues that affordances exist regardless of whether they are seen and notes that making an affordance perceptible is an approach to designing easily-used systems. He notes that the user acts upon what is perceived; however, a *false affordance* may lead users mistakenly to act (depicted in Figure 1).

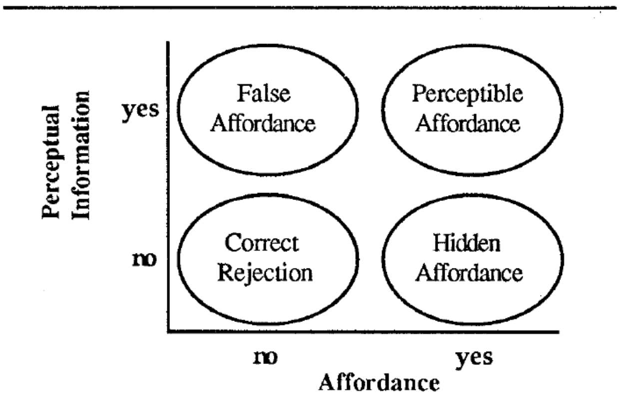

Figure 1: "Distinguishing affordances from the perceptual information about them is useful in understanding ease of use" (Gaver, 1991).

Moreover, Gaver differentiates between temporal and hierarchical affordances, namely sequential and nested affordances (Gaver, 1991; Kaptelinin & Nardi, 2012). Sequential affordances refer to when acting on an affordance to reveal another affordance, and nested affordances refer to seeing an affordance that reveals another (Gaver, 1991).

Even though Norman and Gaver's interpretation and utilization of Gibson's concept of affordances are widely accepted, interpretations of the term are diverse within HCI. Kaptelinin and Nardi (2012) note that many contributions divert from the Gibsonian origins without formally acknowledging this. Thus, they call for a richer understanding of Gibson's concept, as they perceive them as limited in understanding *mediated human actions*. Furthermore, they maintain that considering that HCI is concerned with rapidly developing technology that impacts both humans and society: "[...] this limitation of the framework significantly undermines its ability to serve as a theoretical foundation for studying action possibilities offered by technologies to humans". To address this limitation, they propose the concept of a *mediated action perspective* of technology affordances, where the possibilities of human action and mind are inherently mediated (Kaptelinin & Nardi, 2012). Furthermore, the mediated action perspective questions Gibson's assumption of direct perception. Kaptelinin and Nardi (2012) argue this perspective because humans live in fast-changing, dynamic environments.

2.2.1 Interaction Paradigms: Tangible and Social Computing

Paul Dourish uses *tangible* and *social computing* as umbrella terms for a variety of technologies, and within these are MR. To understand more about MR, Dourish argues that a phenomenological understanding is principal and that both social and tangible computing are essentially rooted in embodiment (Dourish, 2001). The reasoning behind drawing upon theory about tangible and social computing is that these forms of computation, and within this, MR technology, afford people to leverage other skills than when interacting with 2D interfaces, as well as spatial, contextualized, and real-time interaction with virtual objects. Dourish notes that an embodied understanding of the foundation of tangible and social computation should do two things: "inform and support the design, analysis, and evaluation of interactive systems, providing us with ways of understanding how they work, from the perspective of embodiment" (Dourish, 2001, p. 22). Furthermore, he argues that interactions through artifacts are directly embodied in the environment and that tangible and social computing are trying to stitch them back together after being pulled apart by traditional design approaches.

In a brief history of interaction, Dourish (2001) offers us a different view of history. He focuses on the interaction and how interactive systems are incorporated into our world, where the attention is "the human experience of computation". The four phases, or forms of interaction through history, are: **electrical**, **symbolic**, **textual**, and **graphical**. With each new phase, a new human skill or ability is incorporated: "This allows computation to be made ever more widely accessible to people without requiring extensive training, and to be more easily integrated into our daily lives by reducing the complexity of those interactions" (Dourish, 2001, p. 14). Even though the graphical interaction style is largely uncontested, the tangible and social computing approaches are Dourish's true focus. Following Dourish's description, tangible computing can be defined by three trends: 1) Devices with computational power spread throughout an environment have locational and spatial awareness. 2) Augmentation of everyday artifacts so that they respond to their surroundings and people's activities. 3) Instead of using a mouse indirectly and metaphorically (Frutos-Pascual et al., 2019), one can manipulate many objects simultaneously, using both hands, and leverage three dimensions (Dourish, 2001). This interaction method is also called isomorphic mapping interaction (Frutos-Pascual et al., 2019). Isomorphic mappings entail a literal spatial relation between the input action and the system output (Macaranas et al., 2015)

Social computing draws from methods and theory from sociology to design interactive systems. By incorporating information about others and the activity of others, the former "single user"-paradigm is transformed (Dourish, 2001), and the interface has an increased understanding of the context that surrounds it (Dourish, 1999). Dourish's definition of tangible and social computing from a phenomenological point of view aid in supporting his dual argument that: 1) We experience the world by directly interacting with it and act in it by exploring its opportunities, its affordances, and 2) that embodiment is the core element they have in common. Thus, the perspective of social and tangible computing starkly contrasts the Cartesian disembodied mind (Dourish, 2001). Svanæs (2013) argue that all human interaction with technology is embodied. He notes that embodied interaction has often been seen in relation to “avant-garde” technologies and calls for a broader understanding that comprises more mundane technologies. Following this sentiment, technologies such as smartphones and social media are inherently tangible, social, and ubiquitous (Svanæs, 2013).

Steffen et al. (2019) offer three reasons why examining Virtual Reality (VR) and Augmented Reality (AR) through the lens of affordances is applicable: 1) because they help examine user goals by creating a link between features of the technology and the capabilities and goals of the user, and can thus identify why a technology is being used, 2) affordances are relatively generalizable and constant across specific systems. Even though the implementation of AR varies (e.g., through a smartphone or a Head Mounted Display (HMD)), both afford similar possibilities, and 3) because affordances have been applied to IT artifacts and environments, and VR and AR artifacts virtually create and alter environments.

2.3 Mixed Reality

Dourish’s history of interaction shows a gradual move toward a more extensive range of human skills being applied to interact with technology. Metaphorical interaction (Frutos-Pascual et al., 2019), or interaction with interface devices, is increasingly replacing what Dourish calls tangible and social computing. Ubiquitous computing makes the computer itself take a back seat, and we thus move toward more direct manipulation, or more specifically, isomorphic mapping interaction (Dourish, 2001; Frutos-Pascual et al., 2019). In HCI, direct manipulation is understood as both the one-to-one relationship between manipulation and the output result (Macaranas et al., 2015), as well as manipulating a UI with a mouse (Sherugar & Budiu, 2016; Shneiderman, 1983). Following Svanæs’ (2013) argument that all interactive technologies can be seen from the perspective of embodied interaction, MR technologies are a particularly interesting case, considering the close relationship between the bodily input and system output. MR technologies are concrete examples of technologies that utilize direct manipulation of virtual objects, allowing people to use a greater range of skills and abilities.

To classify and distinguish between the various MR systems, Milgram et al. (1995) use the Reality-Virtuality (RV) Continuum (Figure 2).

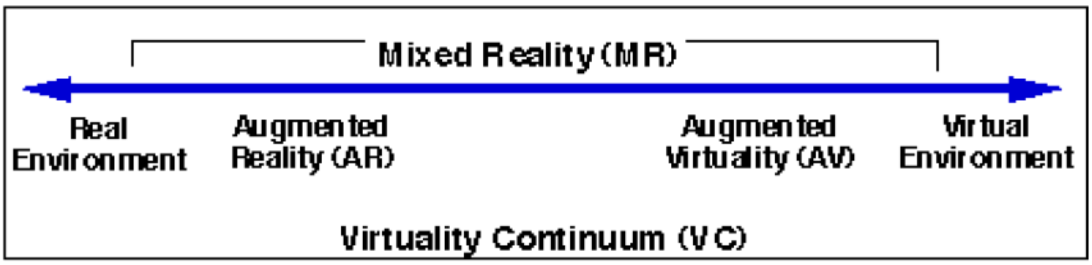

Figure 2: Simplified illustration of the Virtuality Continuum (Milgram et al., 1995).

The far left of the scale depicts a *real* environment that comprises exclusively *real* objects; the other end represents an entirely *virtual* environment that incorporates *virtual* elements only (Milgram & Kishino, 1994). Many attempts have been made to classify the different aspects of the RV continuum and the continuum itself. The continuum thus also goes under names such as Extended Reality (XR) or Spatial Computing (Scavarelli et al., 2021). However, Milgram's taxonomy is perhaps the most used (Doerner et al., 2022). The term MR will, in this thesis, be used in line with Milgram's definition of the concept. It depicts systems and devices along the RV continuum that mix virtual and real objects to varying degrees. MR thus falls between the real and the virtual environment.

Along the continuum comes concepts such as AR and Augmented Virtuality (AV), which are both parts of the umbrella term MR. To define AR, the definition by Azuma (1997) is widely accepted: "[...] AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world" (Doerner et al., 2022, p. 18). Furthermore, AR is not limited to vision but encompass also hearing, touch, and smell (Azuma et al., 2001). MR and AR devices vary immensely in their underlying image input and output technology. HMDs, hand-held devices, and projection-based output devices are regarded as the most common output mediators (Broll, 2022). The different output devices are, in turn, categorized into stereoscopic and monoscopic AR. Stereoscopic AR are devices with separate displays adapted to each eye (Broll et al., 2022). Monoscopic AR depicts devices where a display is viewed with both eyes simultaneously, or the same image is viewed by both eyes, but the perspective is adjusted for only one eye (Broll, 2022; Broll et al., 2022).

2.4 Accessibility

In addressing the research question, accessibility as a concept must be further investigated. This entails how accessibility relates to technology and, more accurately, MR technology. Firstly, a definition of accessibility is provided. This study, encompassing user testing, evaluation, and development, was conducted in Bergen, Norway. Therefore, it is appropriate to focus mainly on European accessibility lawmaking and guidelines. The subsequent sections consider Dyslexia and accessibility challenges, and accessibility and MR.

Disabilities come in several shapes and forms, including sensory, motor, and cognitive impairments (Lazar et al., 2004). To render the world more *accessible*, people with disabilities can utilize assistive technology. In the case of web and user interface (UI) accessibility, Moreno et al. (2009) use ISO 9241-11, the definition of usability, as a starting point to describe accessibility: "[...] usability means designing a user interface that is effective, efficient, and satisfying. Accessibility makes sure the user interface is designed to be effective, efficient, and satisfying for more people especially people with disabilities, in more situations [...]". Hence, accessibility focuses on including people with disabilities, whereas usability affects everyone equally (Moreno et al., 2009). To translate the principles of accessible UIs from high-level goals to concrete design implementations, it is a good start to comply with the Web Content Accessibility Guidelines (WGAG) (Buß, 2020; Lazar et al., 2004). In its current version, WCAG 2.2 contains 87 success criteria that can be used to test whether UIs "[…] meet the needs of different groups and different situations" (Adams et al., 2023). Studies have shown that designing for people with disabilities is beneficial for the public at large (Buß, 2020; Schmutz et al., 2016). When the European Web Accessibility Directive was implemented in Norwegian legislation on February 1., 2023, EN 301 549 and WCAG 2.1 were central in defining the technical demands (*EUs webdirektiv (WAD)*). The European initiative, *Design for All*, says this about accessibility (*The EIDD Stockholm Declaration 2004*):

1. That which is good for people with impairments is often good for everyone else.
2. Accessibility can largely be established by thinking ahead, which means that the preconditions for accessibility can already be created on the drawing board.

2.4.1 Accessibility and XR

This section will look more directly at MR and the affordances of this technology that can be built on to enhance accessibility and, thus, user experience. Lastly, this section will showcase specific use cases of various MR systems in different contexts and then move on to interaction methods afforded by HoloLens 2. The legislations and formal guidelines discussed in Section 2.4 are, first and foremost, for web content. There have been various attempts at defining guides and mapping user needs and requirements for developing MR systems and content. Dünser et al. (2007) explore this by applying HCI heuristics derived from the usability analysis by Molich and Nielsen (1990) to the design of AR systems. The World Wide Web Consortium engaged a working group, *the Accessible Platform Architectures Working Group*, to investigate MR and accessibility (O'Connor et al., 2021). Their approach to mapping needs and requirements covers systems and applications along the RV-continuum and is not specific to any system or technology (O'Connor et al., 2021). The document produced by the working group informs developers and users about requirements that should be addressed in XR environments, challenges related to XR, and accessibility. O'Connor et al. (2021) provide these sentiments to consider when designing XR environments:

1. Understanding specific diverse user needs and how they relate to XR.
2. Successfully identifying modality needs that are not obvious - but still need to be supported.
3. Suitable authoring tools that support accessibility requirements in XR.
4. Using languages, platforms and engines that support accessibility semantics.
5. Providing accessible alternatives for content and interaction.
6. The provision of specific commands within the VR environment (e.g., to go directly to a specified location or to follow another user) which assist with navigation to support different modalities.
7. The use of virtual assistive technologies (e.g., white cane via a haptic device) to provide non-visual feedback.

Furthermore, the document particularly emphasizes *customization* and *personalization* as important factors in an accessible product (O'Connor et al., 2020). Vi et al. (2019) focus on HMDs and present UX guidelines. The area of interest in their work is systems with stereoscopic imaging, which is of particular interest in the context of this thesis. The 11 guidelines are as follows:

1. Organize the Spatial Environment to Maximize Efficiency
2. Create Flexible Interactions and Environments
3. Prioritize User's Comfort
4. Keep It Simple: Do Not Overwhelm the User
5. Design Around Hardware Capabilities and Limitations
6. Use Cues to Help Users Throughout Their Experience
7. Create a Compelling XR Experience
8. Build upon Real World Knowledge
9. Provide Feedback and Consistency
10. Allow Users to Feel in Control of the Experience
11. Allow for Trial and Error

The adaptation of XR and MR technology is becoming increasingly commonplace in various domains and for multiple purposes. Various factors can explain the recent increase in the growth of these technologies. Advances in software and hardware suitable for the consumer market (Frutos-Pascual et al., 2019), such as integrations with operating systems on mobile devices (Scavarelli et al., 2021) and games (Unity, 2022) have been huge drivers. Furthermore, easily available development platforms have also impacted the industry. For instance, some of the development platforms exist as web-based solutions (e.g., A-frame and Mozilla Hubs) and free-to-use platforms and platforms with student licensing (e.g., Unity and Unreal Engine) (Scavarelli et al., 2021). This, in turn, renders them available for people without the means to invest in otherwise expensive equipment and software.

MR has the opportunity to drastically change the way people organize their workspace (Ellenberg et al., 2023). The limitation of physical gatherings through the last years has prompted the use of virtual meeting rooms facilitated by software such as Zoom and Teams (Manuel et al., 2021). However, long before the pandemic, Gaver et al. (1995) had already argued that the traditional office setup for conducting remote meetings lacked several components for a good user experience. A study done by Manuel et al. (2021) shows that virtual meeting platforms need to improve on matters of interpersonal interactions, such as body language and hand gestures, and the strengthening of personal connections. Their research paper presents an alternative approach that leverages XR and embodied interactions to create better arenas for conducting meetings. Ellenberg et al. (2023) discuss that MR technology can support workflow because of its inherent environmental awareness, and that can enable social awareness amongst co-workers. In their research paper, they use the terms *Spatial Coupling* and *Semantic Coupling* to measure and optimize the *Perceived Unity* between virtual content and the physical environment. *Spatial Coupling* describes the placement of virtual content relative to the physical environment, while *Semantic Coupling* is the contextual relationship between virtual content and the physical environment. They argue that for storytelling and presentations, the relationship between virtual content and the referenced object becomes more significant. Their aim is that their terminology may support in the design of MR systems and inspire discussion of universal design in workspaces.

Because of its inherent ability for embodied interaction and, more technically, isomorphic mapping interaction (discussed in Section 2.3), MR technologies are suitable for exploration, learning, and engagement in education. In domains such as health care (Bailly et al., 2019; Balani & Tümler, 2021), industry assembly and production (Hald et al., 2019; Radkowski & Ingebrand, 2017), tourism and museum exhibitions (Han et al., 2017; Koebel & Agotai, 2020; Pietroni et al., 2021), and education (Birchfield et al., 2009; Handosa et al., 2018; Lindgren et al., 2016; Maskati et al., 2021), research and deployment of MR technology are particularly prominent.

Moreover, the increased focus on Universal Design and accessibility – both in the physical and digital sense, has also proved to be enormous drivers. The use of MR technologies to enhance the accessibility of tasks is also prominent in the domains mentioned above. Examples of research and deployment in healthcare are manifold and vary from improving readability for people with cognitive and physical impairments, to phobia treatment, and rehabilitation. Gupta et al. (2019) found that enabling the user to make real-time adjustments to text size, contrast, and typeface decreased reading time for people with dyslexia. The tests were conducted using an AR application on a smartphone (Gupta et al., 2019). Stearns et al. (2018) investigate how to use wearable AR as assistive technology for low-vision users. The prototype, depicted in Figure 3, uses HoloLens as the output device for the text magnification and a smartphone camera as the input device (Stearns et al., 2018).

Figure 3: The AR HMD prototype used to magnify text in the study conducted by Stearns et al. (2018).

Yoon et al. (2019) leverage the capability of smartphones to estimate spatial presence to augment indoor navigation. To cater to the need of users with visual impairments, the assistance is output as haptic, speech, and sound feedback (Yoon et al., 2019). In phobia treatment, Corbett-Davies et al. (2012) and De Witte et al. (2020) employ AR to investigate the effect of superimposing virtual animals and insects into the world and onto users. Corbett-Davies et al. (2012) utilize a camera pointed down at the user's hands and a monitor as the output device. Findings in the research of De Witte et al. (2020) point out that animals visualized through AR can evoke anxiety in people with specific phobias, making AR an appropriate tool for exposure therapy. Flobak et al. (2019) used 360-degree video to stage a scenario to expose the user to public speaking. They argue that these types of VR scenarios have the potential to be helpful in exposure treatment as they are relatively easy to make and are highly customizable. AlMousa et al. (2020) utilized a VR HMD to motivate stroke patients to perform their rehabilitation exercises, and the patients reported that they enjoyed the game and found it accessible and motivating.

Affordances of HL2

Section 2.4.1 exemplified use cases of MR technologies where the embodied interaction plays a central role. As seen in the examples of integration in various domains, MR technology exhibits great potential to enhance accessibility for users. In this research project, one of the main goals is to look at news in the context of MR to enhance accessibility. To understand better in which ways MR technology can do so, it is essential to look at which interaction methods and affordances are made available by MR and not by a 2D medium. The affordances of MR, in turn, strongly relate to the concept of embodied interaction and the opportunities for a more natural and contextualized way of interacting with virtual content. In this section, the affordances of MR, and more specifically of

HoloLens 2 (HL2), are outlined. These encompass HL2's ability to give the user **contextualized representations of virtual objects**, which can be linked to **a sense of presence** (Zhang et al., 2023) and **direct** and **real-time manipulation of virtual content** (Johnson-Glenberg, 2018).

Contextualized representations of virtual objects. In the definition of AR used in this thesis, Azuma (1997) notes its ability to superimpose virtual content into the physical environment. HL2 is an AR HMD utilized for developing the prototype. The HL2 can be classified as *stereoscopic* (Broll et al., 2022). HL2 is a holographic computer that superimposes digital imagery into the physical world that is output in real-time on a see-through HMD (Microsoft, 2023b). The device lets the user directly manipulate the virtual objects. By employing the taxonomy of Milgram et al. (1995) to classify MR systems, it is classified as an *egocentric* immersive system. This classification entails that the system allows the user to feel a sense of **presence** by viewing the world unmediated (not through, e.g., video), where strict conformal mapping of the surroundings is necessary (Milgram et al., 1995). The temporal and spatial nature of HL2 enable more realistic object behavior, such as adding gravity to virtual content. The environmental understanding of HL2 (Table 1) enables contextualization.

Table 1

Environmental understanding of HL2

Name	Description
Six Degrees of Freedom (6DoF)	Allows users to move freely.
Spatial mapping	Maps out the physical environment in real-time.
Mixed Reality Capture	Allows mixing holographic content and the physical environment.

Direct and **real-time manipulation of virtual content.** Furthermore, the affordances of HL2 encompass different interaction methods. Integrated into the device are various sensors to optimize and support the holographic content and interactions with the system. These are as follows: head and eye-tracking, depth sensor, Inertial Measurement Unit (IMU) (accelerometer, gyroscope, and magnetometer), camera, and microphone (Microsoft, 2023b). The system allows for various inputs such as eye and hand-tracking: metaphorical and isomorphic mapping interaction, which are named near and far interaction in the system (depicted in Figure 4), as well as voice commands and iris recognition. The real-time system feedback, or output, is primarily visual. However, the system outputs audio feedback when pushing buttons, moving components, etc., mimicking the sounds they would make if they had a physical form, further supporting the contextualization.

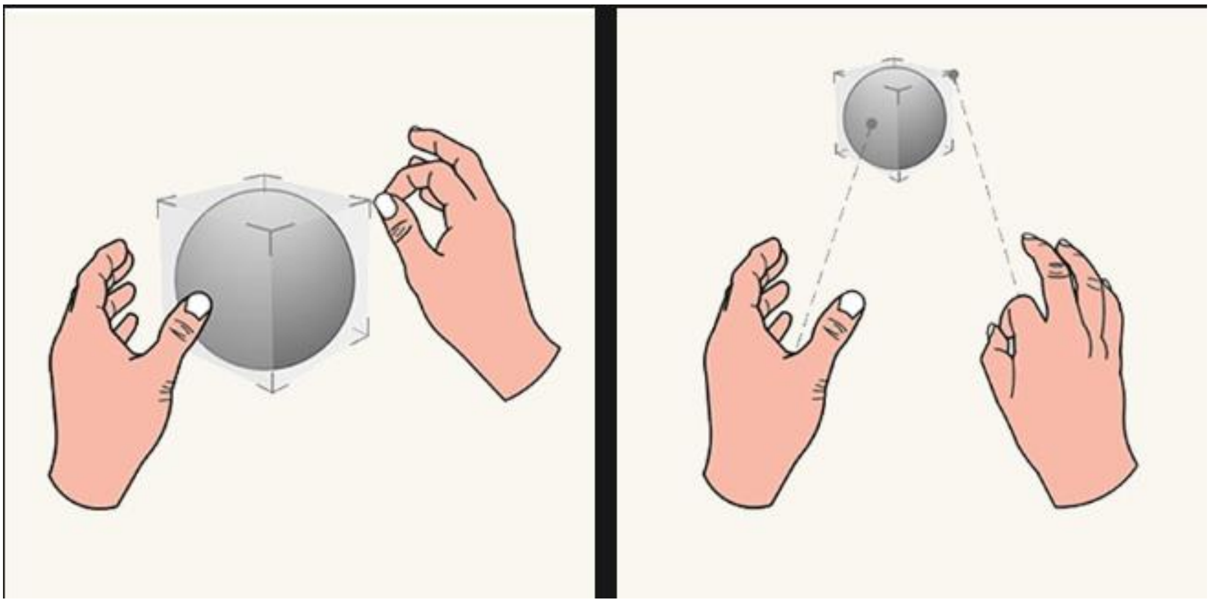

Figure 4: Illustration of different hand interaction methods (Microsoft, 2022d).

Accessibility Challenges Related to HoloLens 2

Both the AR interface and the physical manifestation of HL2 have limitations. Currently, the HL2 device is quite heavy and prominent in its appearance. Some of the affordances MR and HL2 provide may work against accessibility for people with various disabilities. Motion sickness and sensory conflict are instances of this and are essential to counter in MR systems (O'Connor et al., 2021). The HL2 is an AR device, which entails that the user is not fully immersed in a virtual reality. This may help to counter motion sickness. However, flashing images is something that must be considered. The refresh rate of the HL2 is 60 Hz, making it usable for people with epilepsy (Microsoft, 2021). Furthermore, the Field of View (FOV) is limited to 52 degrees, which may pose difficulties and limit the user's sense of immersion and flow. Most functionality can be accessed by only using one arm. Additionally, voice commands and gaze interaction can be utilized, making it somewhat accessible for people with one or no arms or hands.

The documentation of Mixed Reality Tool Kit (MRTK) version 2.8, the version utilized in the prototype, does not contain any accessibility guidelines for developing accessible applications or any built-in features that claim to enhance accessibility. However, the next generation of MRTK, the generation 3, Microsoft plans to implement more accessibility features. MRTK3 has yet to be released but is in an open beta for developers to test and provide feedback (Microsoft, 2023a). To enhance accessibility, an accessibility package is added to the open beta (Microsoft, 2022a). The package contains, at this point, two features: *Describable Object* and *Text Accessibility*. *Describable object* will enable screen readers to recognize objects and describe their visual qualities and spatial location to the user. *Text Accessibility* will render text more readable for people with visual impairments by color inversion and readable from any angle.

2.4.2 The Importance of Accessible News

News use has a democratic significance in our society and has long been referred to as the "public watchdog" (Picone, 2007). Moe and Ytre-Arne (2022) argue that the role of news has a substantial impact on how the political sphere connects to the lives of citizens. In democratic societies, the news keeps the public informed about the world and cultivates public engagement (Moe & Ytre-Arne, 2022; Nordberg & Guribye, 2023). On the other hand, media outlets can act as gatekeepers and agenda setters and withhold or decide which news are covered (Picone, 2007). Furthermore, news consumption has evolved from being a passive activity to being active and engaging in nature (Nordberg & Guribye, 2023; Picone, 2007). Moe and Ytre-Arne (2022) call for ventures outside the mainstream to cater to the complexities of media use. Not accounting for various degrees of disability is a missed opportunity for media outlets to engage all citizens in public discussion. Venturing outside mainstream news outputs, as Moe and Ytre-Arne (2022) call for, may thus be beneficial for people with disabilities such as dyslexia.

2.4.3 Dyslexia and Sensory Cues

This research project is not a study about dyslexia per se. However, having the core sentiment of accessibility and *Design for All* in mind, being mindful of this group of users may prove invaluable for developing accessible MR applications that concern reading, also for people without dyslexia. Dyslexia is characterized by severe deficits in reading and spelling (Cavalli et al., 2019) and is not interdependent on intelligence (Shaywitz et al., 2021).

Studies show that text comprehension when reading digitally presented texts is lower for people with Dyslexia than for those without (Cavalli et al., 2019; Mangen et al., 2019). Furthermore, Cavalli et al. (2019) report that when reading a physical book, people with Dyslexia at university level education perform equally to non-dyslexic people. According to Mangen et al. (2019), this can be attributed to the fact that readers, and dyslexic readers in particular, are reliant on various cues afforded by manipulating a physical medium, like a book. Examples of the sensory cues afforded by a book can be both haptic and visual. The act of turning a page, feeling a book's weight to estimate the number of pages read, or tracing words with a finger to stay oriented are examples of haptic cues (Cavalli et al., 2019; Mangen et al., 2019; Stearns et al., 2018; Watson & Wallace, 2021). Visual cues such as page numbers and seeing the visible signs of the length of a text also impact the reading experience (Cavalli et al., 2019; Mangen et al., 2019). To mitigate the difficulties when reading digital texts, several digital aids have been proposed, such as visual and haptic cues like digital rulers or tracing sentences with the cursor to mimic the act of tracing words with a finger (Stearns et al., 2018; Watson & Wallace, 2021), context supporting components such as maps, images and graphs (Schnotz, 2002), and sidebars containing metadata (Cavalli et al., 2019). Additionally, adequate inter-letter, inter-word, and inter-sentence spacing (Galliussi et al., 2020) and choosing appropriate typography (Galliussi et al., 2020; Marinus et al., 2016) will constructively implicate text comprehension.

3 Research method

3.1 Research through Design

This project was conducted following an RtD approach. RtD consolidates scientific research with design practice to generate new knowledge (Zimmerman & Forlizzi, 2014). The method relies on the interaction design process. However, it is more systematic and requires more documentation of the steps taken (Zimmerman & Forlizzi, 2014). Furthermore, the research outcomes should be novel, not just refinements of existing research or artifacts (Zimmerman et al., 2007), and the research itself often engages with problems that cannot easily be reduced, also called "wicked problems" (Zimmerman et al., 2010). To further describe a "wicked problem," Rittel and Webber (1973) bring forth the tension between social values and the needs of individuals as an example: "[…] diverse values are held by different groups of individuals-- that what satisfies one may be abhorrent to another, that what comprises problem solution for one is problem-generation for another".

Developing an AR application for reading news might not be a wicked problem. Still, this project deals with different stakeholders, tensions, and constraints, making it appropriate for RtD to be applied. Some examples of this, and that are considered throughout the project are:

1. The tension between making a system designed for people with dyslexia – will the visual cues implemented in the prototype be experienced as a nuisance for people without Dyslexia, or will they act as aids for the broader public?
2. The implications of designing for an emerging/not fully realized technology:
    a. Do the guidelines of WCAG need to be altered to fit this design space?
    b. Considering that the technology is expensive, will this implicate a wide acceptance in the general public and, in turn, inhibit news outlets and media houses from investing in such technology?

The RtD approach emphasizes the design outcomes as something that can transform the world from its current state to a preferred one, and: "The final output of this activity is a concrete problem framing and articulation of the preferred state, and a series of artifacts—models, prototypes, products, and documentation of the design process" (Zimmerman et al., 2007). To conduct a RtD project, Zimmerman and Forlizzi (2014) propose five steps (depicted in Figure 5): *select;* choose a research problem and *design;* conduct design activities, *evaluate;* continually challenge the initial framing, *reflect and disseminate;* demonstrate or present findings to others for further reflections and validation of the results, and lastly, *repeat* the steps.

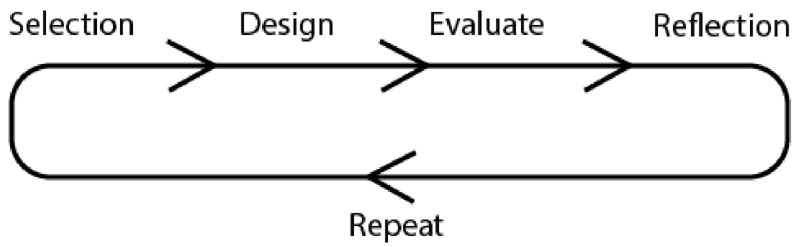

Figure 5: An illustration based on Zimmerman and Forlizzi's (2014) suggestion of how to carry out a RtD project.

Big societal issues, shifts in design practices, research, and theories throughout history are adding complexity to the democratization of IT use and innovation (Bardzell, 2018). To aid in this democratization, user involvement in the design process, particularly the practice of Participatory Design (PD), is imperative (Bardzell, 2018; Bødker & Kyng, 2018). PD differs from other human-centered design approaches by emphasizing the user as a co-designer throughout a project and the sharing of power between the user and researcher (Bratteteig & Wagner, 2014). From its beginnings, the goal of conducting PD has been to empower the user and contribute to a more democratic society (Bødker & Kyng, 2018). Thus Bardzell (2018) argues that PD is one of the most successful practices for supporting these democratic values. The project's overarching goal is to investigate how the affordances of MR technology can be used to enhance accessibility in digital news articles. Seeing that MR use cases vary greatly and that the systems are complex makes this an appropriate opportunity to leverage PD. The role of news in our society is to inform the public about current events and act out its role as the "public watchdog" (Picone, 2007). The need for news to be accessible to all citizens is vital for democratization, which, in turn, makes PD applicable. Additionally, in line with the sentiment of "*That which is good for people with impairments is often good for everyone else*" (*The EIDD Stockholm Declaration 2004*), involving users with impairments is beneficial. O'Connor et al. (2020) note that involving users with various degrees of disabilities is advantageous because it can help showcase affordances available to the user, making them evident and understood. Furthermore, to support the PD process, it is highly beneficial to utilize prototyping for demonstrations, exploration, and evaluation to people outside of the design group (Bødker & Kyng, 2018).

3.1.1 Sample

Participants for the design activities and user evaluations were sourced from the University of Bergen (UiB) Campus, the UiB IT department, and through referrals. In the formative testing, it was decided to focus on IT experts, early adopters, and university students with and without the diagnosis of Dyslexia. This type of sample can prove helpful in the early development phase of a project (Baxter et al., 2015). The decision to include participants with and without the diagnosis was made early on, as a more comprehensive selection of people to participate would benefit the project. For this project, sourcing participants from a university campus, and more precisely, the Department of Information Science and Media Studies, had the potential to make it easier to get a larger pool of viable participants. The rationale behind this was founded on the assumption that many students studying Information and Media Science are interested in new and emerging technology. The same goes for IT professionals. Twelve participants participated in total. One of the participants with dyslexia was recurring in all four prototype evaluations, while three were part of two evaluations. The rest of the participants took part in only one evaluation.

3.1.2 Analytical Frameworks

The Anatomy of Prototypes

The artifact to support the RtD process in this project is a prototype developed through an evaluation process of four iterations and was developed in collaboration with a co-student. To define the evolution of the prototype throughout the various iterations, the anatomy of prototypes presented by Lim et al. (2008) is utilized as an analytical lens. The earliest iteration of prototyping started with a proof of concept in a pre-study (Sviland & Tveranger, 2022a) using a low-fidelity prototype, then moving over to workshops, usability testing, user observation, and testing, all of which were carefully documented in field reports (Sviland & Tveranger, 2022b, 2022c). This research project is built on the five-step model to carry out RtD projects described by Zimmerman and Forlizzi (2014), depicted in Figure 5.

Prototypes are used to learn about, discover, generate, and refine designs (Lim et al., 2008). Lim et al. (2008) argue that what *manifests* the prototype itself affects the outcome of exploring the design space. Additionally, *filtering* the qualities the designers are interested in will lead to a less distorted understanding (Lim et al., 2008). Thus, they propose that it is a goal in and of itself to be thoughtful about choices made when developing the prototypes and an *Anatomy of Prototypes* to describe these deliberate choices. Table 2 briefly summarizes the elements of the anatomy:

Table 2

The Anatomy of Prototypes

Dimensions	Definition	Example Variables
Filtering	Appearance	Size; shape; proportion
	Data	Data size; data type; privacy
	Functionality	System function; users' functionality needs
	Interactivity	Input behavior; feedback behavior
	Spatial Structure	Arrangement of interface elements; relation between elements
Manifestation	Material	Medium used to form the prototype
	Resolution	Level of detail
	Scope	Level of contextualization

From "The Anatomy of Prototypes: Prototypes as Filters, Prototypes as Manifestations of Design Ideas" by Lim et al. (2008).

Thematic Analysis

In order to identify and extract patterns from the user evaluation sessions, it was decided to utilize thematic analysis (TA). The TA was conducted by an inductive approach following the six phases of thematic analysis, described by (Braun & Clarke, 2006), and done in collaboration with the prototype co-developer. Utilizing TA in an inductive approach means that the researcher does not try to fit the data into existing frameworks (Braun & Clarke, 2006). The combination of conducting inductive analyses and utilizing the contextualizing framework from Lim et al. (2008) may help to validate results, formulate a more structured project and help mitigate research bias (Streefkerk, 2019).

By the end of each iteration, during the reflection phase of RtD, the evaluations were 1) *familiarized* with through transcribing the audio recordings from the user evaluations. Notes were taken throughout this process, and both participants read through the transcriptions to avoid missing important events. 2) *Initial codes* were generated from the data, followed by 3) a search for common *themes* amongst the codes. Subsequently, 4) the themes were *reviewed* and rearranged, and clustered on a Miro-board (*Miro*). In stage 5), *defining and naming themes*, some of the themes were re-organized as sub-themes, which helped support the context of the overarching theme. Lastly, 6) a field *report* was produced.

3.1.3 Data Collection

Table 3 briefly describes the activities carried out during the RtD-process (Figure 5).

Table 3

Overview of the various RtD-activities in the data collection

Iteration (Ix)	Activity	Method	Quantity (Duration)	Description
I1 (Pre-study/proof of concept)	Selection	Lecture and discussion with experts	3 hours	Presentations followed by discussions between students and domain experts such as NRK, media houses, and media experts in Norway.
		Literature review	5 days	Conducting a literature review on the target group, accessibility, and the state-of-the-art of MR projects and accessibility.
		Lecture and Q&A with experts	1,5 hours	A presentation was followed by a discussion led by the head of *Dysleksi Norge* on the diagnosis of dyslexia and personal experiences.
		Target group Interviews	5 sessions lasting 20 minutes	Semi-structured Interviews with the target groups: people with dyslexia and early adopters of digital technology.
	Design	Prototyping	14 days	Design activities to develop a mock-up to present a proof-of-concept to users.
	Evaluation	Use Case Workshop	5 sessions lasting 30 minutes	Exploration/formative testing of the mock-up.
		Interviews	5 sessions lasting 30 minutes	Semi-structured interviews where both specific parts of the mock-up and accessibility aspects and user experience were discussed
I2	Selection	Review of field report from I1	2 hours	Review of report to inform design activities and design decisions.
	Design	Designer workshop	1 hour	Design activities were conducted in two short sessions by both prototype developers.
		Design workshop	2 workshops with a total of 7 participants (40 mins. each)	Semi-structured workshops with IT experts and interaction design students to get input on how they envision the design of an MR environment for presenting news.
	Evaluation	Concept-demonstration	2 workshops with a total of 7 participants (20 mins. each)	Demonstration and discussion of the designs produced in the designer workshop.

	Reflection	Field report	1 week	The findings were analyzed using Thematic analysis and presented in a field report.
I3	Selection	Review of field report from I2	2 hours	Review of report to inform design activities and design decisions.
		Literature review		MS HL2 documentation on accessibility and best practice regarding design decisions.
	Design	Prototyping	6 weeks	Exploring potential approaches and framing the prototype's (MVP) scope from the findings from I2.
		Prototyping: development sprint	4 weeks	Implementing design decisions from the design process.
	Evaluation	User evaluation of prototype	3 sessions lasting approx. 30 mins. each	User test of the prototype. The users were all tasked to read the article and explore the prototype.
		Interview	3 sessions lasting approx. 30 mins. each	Semi-structured interviews regarding the user experience of the prototype.
I4	Selection	Review of field report from I3	2 hours	Review of report to inform design activities and design decisions.
		Literature review		MS HL2 documentation on accessibility and best practice regarding design decisions.
	Design	Design workshop	3 hours	Using a structured approach consisting of three tasks, the results from the prior evaluation were concretized in design decisions.
		Prototyping: development sprint	2 weeks	Implementing functionality and design grounded in the results from the design workshop.
	Evaluation	User evaluation of prototype	7 sessions, lasting approx. 30 mins. each	Participants were given two practical tasks to evaluate the prototype while "thinking out loud".
		Interview and discussion	7 sessions, lasting approx. 30 mins. each	The semi-structured interviews consisted of going through each prototype component, then moving on to questions regarding self-assessment and more general questions regarding the user experience.

This chapter has summarized the sample of participants, the analytical frameworks applied, and summarized the data collection process. The results of the activities in the iterations were discussed, reflected upon, and documented in field reports. Chapter 3 will explore the design activities, user evaluations, and findings in greater detail and provide descriptions of the prototypes utilizing the framework by Lim et al. (2008).

4 Research through Design Process – The Evolution of MRnews

In Chapter 3, the RtD process was described, and the data collection activities this research project comprises were briefly outlined in Table 3. This chapter will discuss the process and activities in more detail. Each iteration followed the structure presented in Figure 5 and was subsequently summarized and reflected upon in field reports (Sviland & Tveranger, 2022a, 2022b, 2022c). Furthermore, the reports were used as input for the following iteration. As a result of developing most of the prototypes in the 3D game engine, *Unity* (Unity), terminology from the application will be used throughout this thesis. *Scene* is a term from Unity that describes the asset encompassing all the parts of a game or application (Unity). The term *scene* is used in this thesis to describe the prototype layout comprising all the *components*. The term *component* is derived from MRTK's prefabricated components (prefabs) and is used here to denote the different content boxes placed throughout the *scene*.

Iterations 1 through 4 are depicted in this thesis in the same structure as they were conducted, namely by *selection*, *design*, *evaluation*, and *reflection*. Following this structure, the activities are described in-depth, and the prototypes are described utilizing Lim et al.'s (2008) prototype anatomy (Table 2) to showcase the progress throughout the iterations.

4.1 Iteration 1 – Proof-of-Concept

The first iteration is defined as a pre-study and proof-of-concept phase. Since MR technology is not very well thread territory amongst casual users, the assumption was that it would be appropriate to build something that could be visualized and presented to users. Presenting a prototype in HL2 would help the user better understand the technology's possibilities and affordances. This first implementation also provided insight into how first-time users handled interaction with the HL2 system. The *selection* phase, comprised of a literature review, two lectures and discussions with experts, and a target group interview, acted as a starting point and informed the design process and the evaluation. The *design* process for this iteration involved prototyping activities, and to *evaluate*, a use case workshop followed by interviews was deployed. Lastly, a field report (Sviland & Tveranger, 2022a) was made to sum up the results from the evaluation and *reflect* upon the iteration.

4.1.1 Selection

Gaining domain knowledge

To acquire domain knowledge, lectures and talks by several media houses and media professionals situated in Norway were arranged by the Department of Information Science and Media Studies at UiB were attended. Notably, the lecture by NRK (Norsk Rikskringkasting), the public broadcaster in

Norway, inspired this project’s problem and design space. The lecture and the following discussion mainly focused on user needs and NRK’s web platform’s challenges regarding the tension between engagement and accessibility in their news articles. According to NRK’s user research, adding extra visual elements to news articles, such as parallax scrolling and animations, may cause discomfort to some users. People with dyslexia were mentioned as a group that, in some cases, were alienated because of this. This led to an interesting problem space to explore further. A meeting and a talk were arranged with *Dysleksi Norge*, a foundation for people with dyslexia in Norway, to gain further insight into the condition and user requirements related to it. The talk outlined challenges people with dyslexia encounter daily pertaining to education, general text comprehension, and which tools are used to overcome these challenges. The talk was concluded with a Q&A with the audience.

The established media houses in Norway had, at this point, limited knowledge of MR or recourses to explore the use of MR on their platforms. A review of existing literature was conducted to gain insight into the state-of-the-art of various applications of MR and research on accessibility challenges and opportunities when developing and using such systems. Drawing upon NRK’s user insight, dyslexia and accessibility challenges related to the diagnosis became the focus of Iteration 1.

4.1.2 Design

Prototyping

The user research provided valuable insights into what information the prototype should contain. The lack of visual cues, which is a considerable challenge in the context of text comprehension for people with dyslexia (Cavalli et al., 2019), set the baseline for the design. A low-fidelity prototype was developed using pre-existing HL2 components.

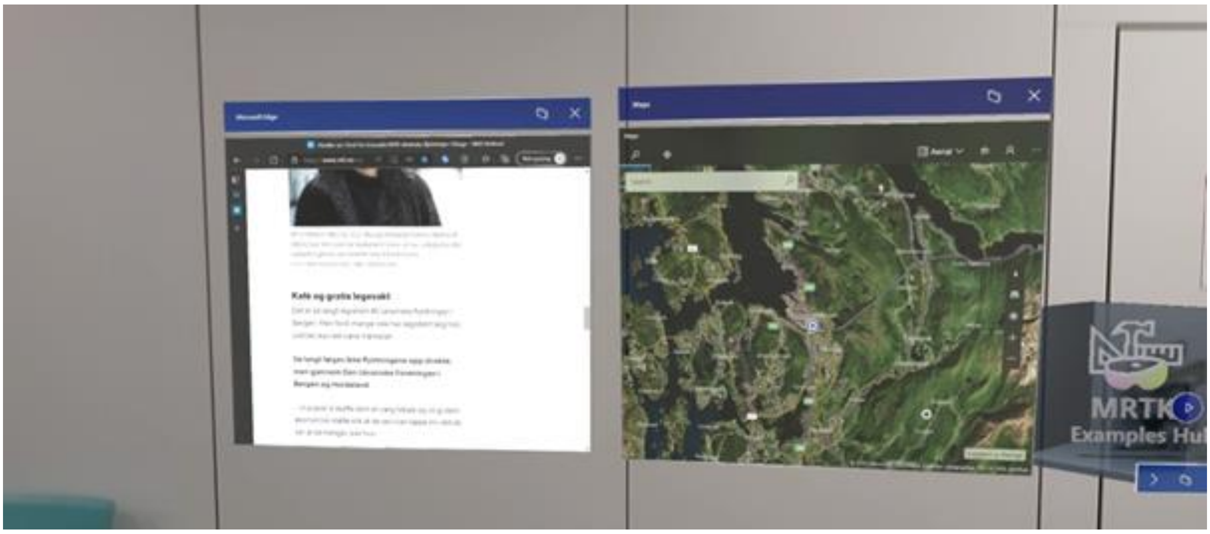

Figure 6: The prototype per Iteration 1.

The prototype consisted of a map with predefined map markers and a news article in a browser window, as depicted in Figure 6. The map with map markers acted as the visual cue in this iteration. At this stage, the map and the article were not connected in any way other than that the pinpoints on the map reflected the locations mentioned in the article. The map supported text comprehension in several ways. Firstly, as a way to stay oriented: the map markers acted as a visual summary (Cavalli et al., 2019; Mangen et al., 2019) of the locations mentioned in the article; lastly, for engagement and exploration where physical engagement would hopefully lead to better memory retention (John et al., 2022; Lindgren et al., 2016). The prototype's fidelity at this stage reflected its intended purpose: the formative testing of a concept presented in an AR environment and for showcasing the built-in interaction methods of HL2. In other words, it was simple by design to easier examine novice users' first encounter with the system. Table 4 describes the prototype based on Lim et al. (2008)'s anatomy of prototypes:

Table 4

The anatomy of the prototype by the end of Iteration 1

Dimensions	Definition	Variables
Filtering	Appearance	Two squares, approx. .5x.5m, one containing the map and the other containing a browser.
	Data	One of the components contains a map with data such as location names and map markers. The other component includes a browser window with a news article from NRK. The article contains text, video, links, and images.
	Functionality	Both the map and the browser window containing the article are scrollable and zoomable. The map also allows for additional map markers to be added or deleted. The browser window allows browsing the web, reading the article, scrolling the page, and clicking links and videos.
	Interactivity	The prototype utilizes all the interaction methods possible in HL2. However, hand interaction is the method in focus. This comprises both *near* and *far* interactions, as exemplified in Figure 4. Voice commands can be used to close components but not to interact with their contents. The built-in sound system feedback is also enabled and is activated when pushing buttons, moving components, etc.
	Spatial Structure	The default positioning of the two components is side-by-side, at eye level, from a sitting position. The components are approximately the same size. The user may alter both placements and their sizes.
Manifestation	Material	The holograms are projected onto the physical display of the HL2.
	Resolution	The level of detail is relatively low at this point. The prototype includes a map with limited possibilities for interaction and a browser window displaying a news article. System feedback is fast, considering that the components are out-of-the-box HL2 components. The level of detail in the

	appearance of the components is high, even though they are simple in functionality. The data in the prototype is actual data generated from a news article and Google Maps.
Scope	What is being tested in Iteration 1 is mainly the concept of reading a news article through a MR system, how the participants react to the interaction methods in HL2, and when combining these two, which aspects can be altered/enhanced to make the experience more enjoyable.

4.1.3 Evaluation

Use Case Workshop and Interviews

The workshops were carried out with five participants aged 20-36. This age span was chosen assuming that people in this age group are generally more accepting of new technology and are more likely to be early adopters (Baxter et al., 2015). To make inquiries regarding whether AR/MR technology could be of aid when reading digital news articles, people with the diagnosis of dyslexia were also part of the target group for this workshop. Successfully achieving accessibility will also benefit a more significant portion of the population. Out of the five participants, two self-reported that they had dyslexia.

The participants were first tasked to read a news article from NRK on a desktop computer. After reading the article, they were asked questions related to the experience (Appendix A). This was done to create a baseline for comparing reading an article on a desktop to experiencing it in MR. Before exploring the prototype, the participants all got a chance to get acquainted with the HL2 system. This was done by allowing the participants to get familiarized with interaction methods in the *MRTK2 - Hand interaction examples* (Microsoft, 2022c), depicted in Figure 7. Since the participants were all novice users, this step was crucial in order to complete the following task with as few distractions as possible. Lastly, the participants were asked to read a news article presented in HL2. The workshop concluded with an interview related to the experience.

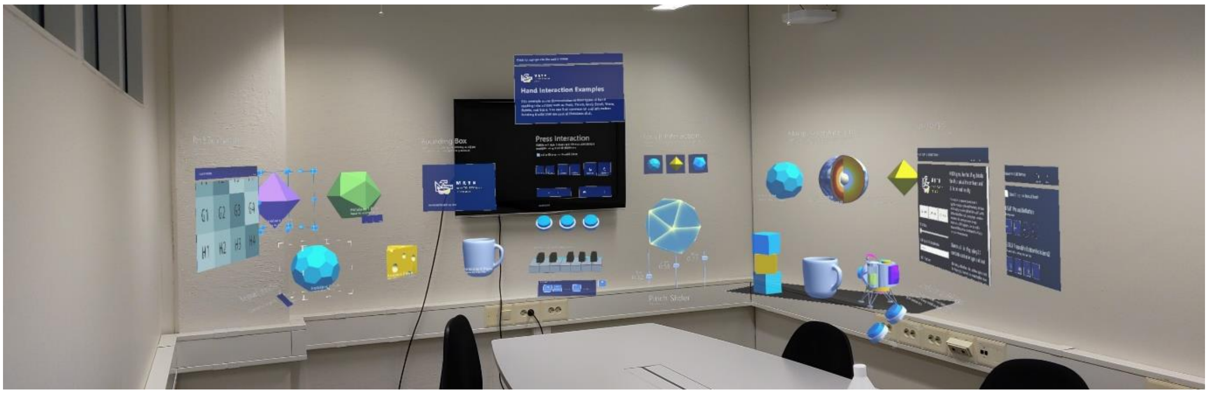

Figure 7: Illustration of MRTK2 - Hand interaction examples.

When analyzing the findings from the use case workshop, some recurring themes were identified: **issues regarding interacting with and navigating the system and HL2**, **not leveraging the strengths of MR**, **stress/distraction**, **learning curve**, and general **positive remarks**.

Issues regarding interacting with and navigating the system and HL2: All the components used in the prototype were "out of the box" from Microsoft. This made focusing on the participants' interaction with the system easier, as it was not clouded by new design or functionality. Consequently, it allowed for a less obfuscated view of what the users found challenging. It was noted that all the participants struggled with hand interactions and navigating the contents of the components. This could be attributed to a few things. Firstly, the participants were unfamiliar with this interaction methods. interaction from afar, was particularly demanding, but they also struggled to some extent with direct object manipulation. Secondly, the browser and map were sub-optimal for HL2: the built-in keyboard was hard to navigate, and the buttons in the components were too small. Neither component was adequately designed for a MR experience and did not draw on the strengths of the HL2 system. Related to the physical manifestation of HL2, some participants noted that the device was clunky and heavy on the head.

Not leveraging the strengths of MR: The map component did not leverage HL2's potential regarding interaction or how it was presented visually. Instead of taking advantage of the interactions afforded by the system, the zoom functionality was enabled by two buttons placed to the far right on the map (Figure 6). Moreover, the map was visualized as a flat surface, mimicking a map presented on a 2D surface such as a desktop computer. In this manner, the map could just as well have been presented on a desktop without the hassle of learning to navigate a MR system. The interest in exploring the map varied amongst the participants. Nonetheless, there was an agreement that if the map had contained more information and was more interactive, it would have been a more interesting and engaging component.

Stress/distraction: Nearly all of the participants mentioned that they felt distracted when they made errors, and this, in turn, made them lose their concentration when reading the article. One of the participants noted that because of the mistakes they made, it was hard to concentrate, which subsequently made them reluctant to explore the prototype. Another participant pointed out that the text was hard to read, which made it hard to focus on the article.

Learning curve: None of the participants ascribed the errors made, or the difficulties they had navigating the system and the components, to the system itself. Instead, they attributed it to their capabilities and their limited time interacting with it. Even though misclicks and hand interaction errors caused the participants frustration, they all concluded that the system had a learning curve and that issues like these would cease to be as prominent after more time spent interacting with the system.

Positive remarks: All participants stated that the map positively impacted their experience except for one. Three mentioned that it helped visualize the article's content, and one said it was beneficial for memorizing it. Two participants clearly stated that an interactive map would make the experience more immersive. Another positive remark was toward the system's spatial opportunities and the fact that one can read the news article both standing or sitting and not being dependent on a surface to place a device upon. Furthermore, they were all excited by the technology and curious to see its future potential.

4.1.4 Reflection

Deploying a low-fidelity prototype in use-case scenarios can prove valuable in uncovering unanticipated challenges (Zimmerman et al., 2007). Even in the formative stages of an RtD-process, this may yield valuable information (Lazar et al., 2017), as did it in this stage of the research project. Some concrete aspects to improve upon were uncovered during the user evaluation:

Better legibility: partly because of limitations in HL2, reading black or dark text on white backgrounds is uncomfortable. Microsoft has developed specific guidelines to optimize the experience (Microsoft, 2022b), which will be taken more into consideration in the next iteration.

Interactivity: For quick deployment, the prototype was intentionally scaled back. The participants voiced a desire for more interactivity and more content to explore.

Leveraging the affordances in HL2: Utilizing the room (spatial design) and having the possibility to move around and using the appropriate interaction methods to enhance ergonomics and accessibility when possible. Additionally, leveraging more on the three-dimensional nature of the holograms will elevate the experience and differentiate it from interacting with a desktop computer, a phone, or a tablet.

4.2 Iteration 2 – Low Fidelity Prototype

For this iteration, it was decided to scale the prototype back in fidelity. This was done to better understand how the participants envisioned reading news in an MR environment without having a preconceived notion of it. The scope for this iteration was selected by reviewing the field report from Iteration 1. This inspired the activities, which led to a designer workshop conducted by the prototype developers. The results of the designer workshop accumulated into a low-fidelity prototype (Table 5) and inspired the contents of a design workshop conducted with users. Lastly, a concept demonstration and evaluation were performed utilizing a low-fidelity prototype. A report

(Sviland & Tveranger, 2022b) reflecting on and analyzing the design process and evaluation was written and is summarized throughout Section 4.2.

4.2.1 Selection

As mentioned, reviewing the field report from the previous iteration acted as user research. The findings inspired concrete design strategies and laid the grounds for the design activities. From the former evaluation phase, it became apparent that the participants were not aware of the opportunities of MR technology. This may be attributed to the fact that AR HMDs are not as widespread as VR HMDs. This insight inspired the design activities.

4.2.2 Design

Designer Workshop

The first design activity for the second iteration was a designer workshop where the author and the co-developer of the prototype conducted a design sprint. The aim of the sprint was to concretize the results from the former iteration into a design. A speculative design approach was applied, where a utopian use-case scenario was sketched on paper. The prototype, depicted in Figure 8, was later evaluated by users (Section 4.2.3) and is classified as the prototype for Iteration 2. The prototype is described in Table 5.

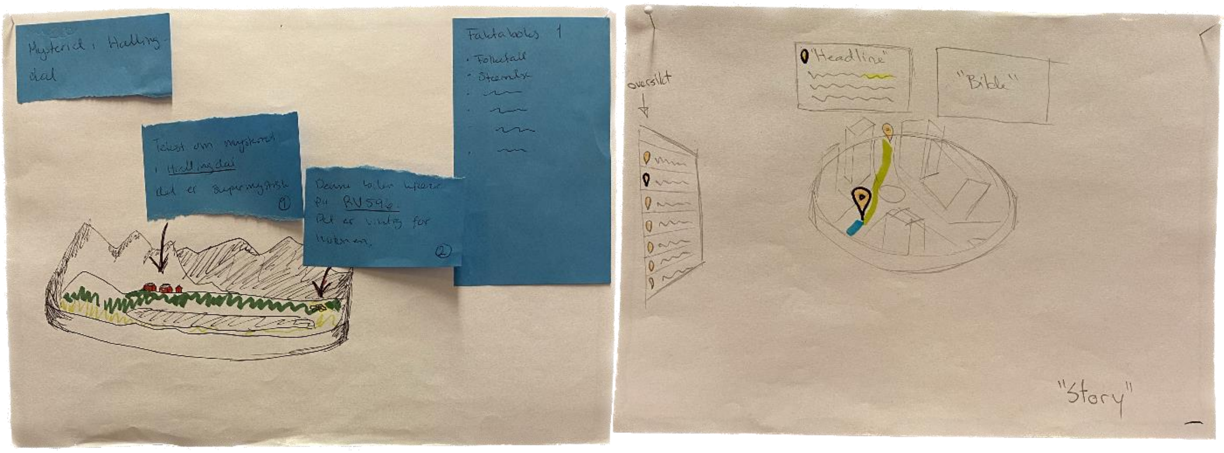

Figure 8: The prototype by Iteration 2.

Table 5

The anatomy of the prototype by Iteration 2

Dimensions	Definition	Variables
Filtering	Appearance	Two A4 sheets of paper with drawings and Post-its acting as interactive components.
	Data	A visual representation of a map and written text.
	Functionality	A representation of the use-case with a map as a central component that simulates the different opportunities of interaction and information visualization.
	Interactivity	Interactive by manually adding or removing the post-its. This simulates a click or selection of the elements in the map.
	Spatial Structure	2D representation of a MR/AR environment.
Manifestation	Material	Paper
	Resolution	The level of detail is lower and scaled back compared to the prototype in Iteration 1. Slow system feedback and low detailed appearance. The data in this prototype iteration is faked to create a more controlled use-case scenario.
	Scope	The focus is on an inter 3D map supporting an article in a MR/AR environment. The hypothesis is that the map will enhance accessibility by acting as context support.

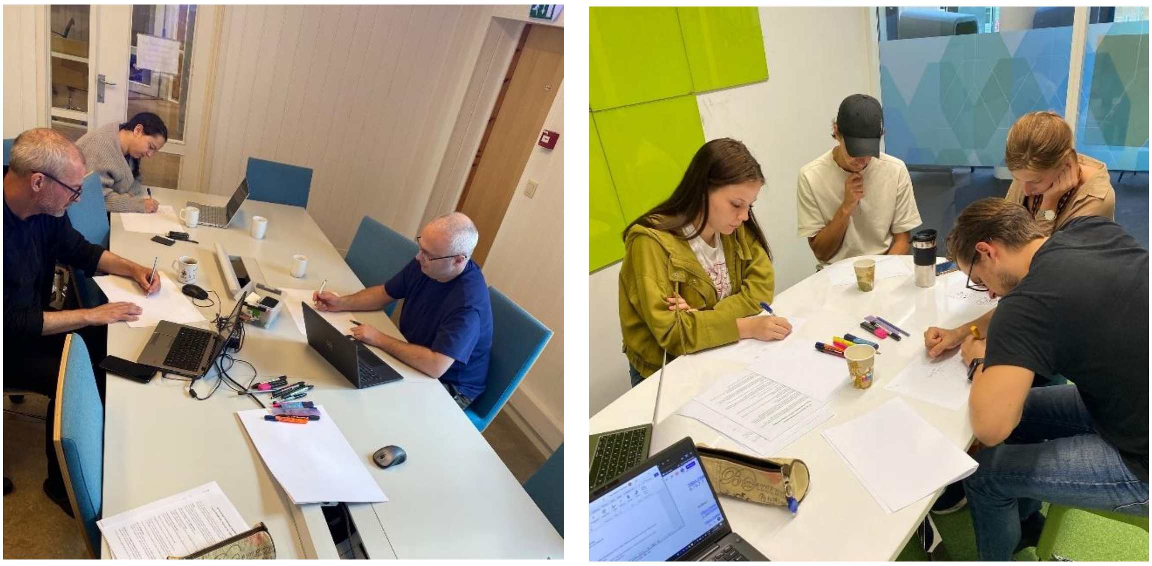

Figure 9: The design workshops and user evaluations for Iteration 2.

Design Workshop

In August 2022, two workshops (Figure 9) were conducted with seven participants. The participants in the first workshop consisted of three IT professionals, aged 40 to 50, who were interested in new digital technology. All the participants were caught up to date on emerging technology. The second workshop consisted of four students on master's degree level, aged 23 to 27 years old, all interested in and caught up to date on emerging technology.

The workshops were divided into three segments. The participants were first shown a two-minute video by Microsoft, introducing them to MR/AR and HL2. Furthermore, we discussed how to interact with objects in HL2. The purpose of this introduction was to give the participants information and inspiration to solve the upcoming assignments. Next, they were tasked with reading a news article, which laid the foundation for the last task: to represent the news article's content in an AR environment, drawing upon the affordances of the technology. Subsequently, they were asked to visualize their thoughts on paper by drawing or writing them down (Figure 10). One by one, the participants explained their concept drawings. The participants and the researchers successively discussed the concepts.

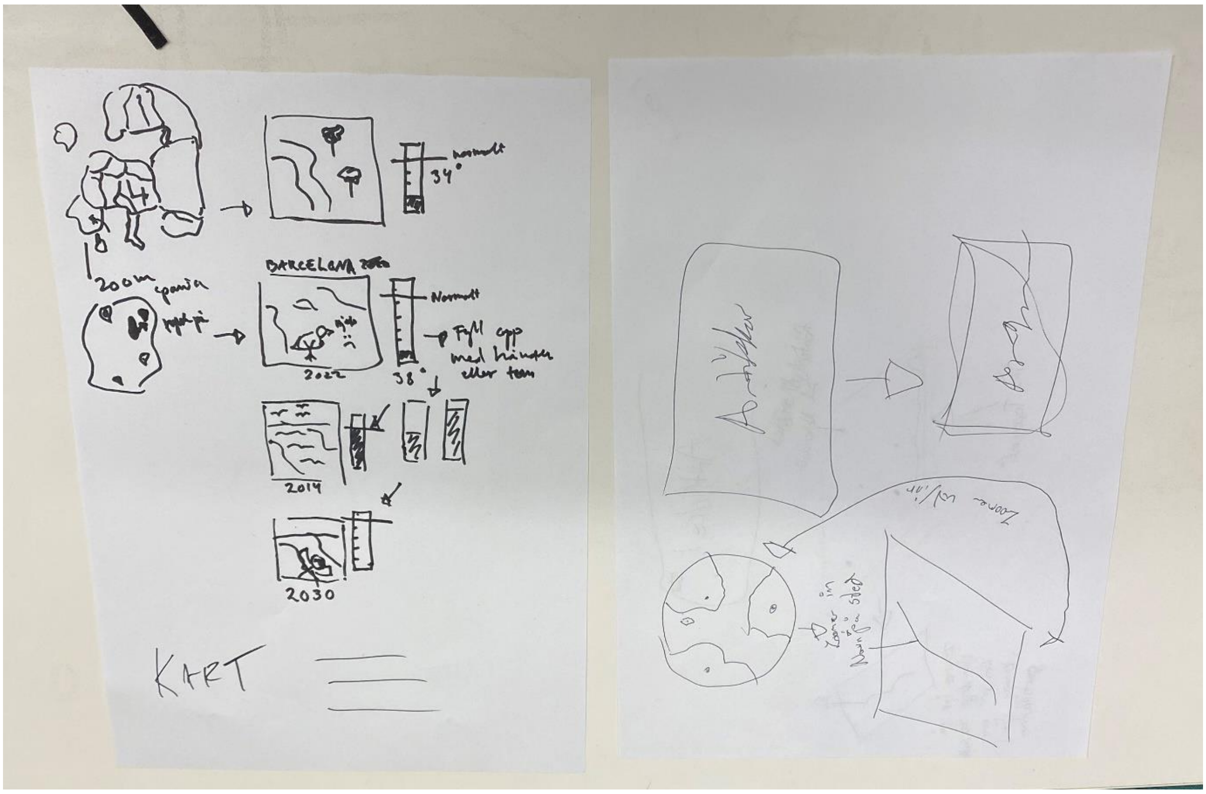

Figure 10: Concept drawings from the first workshop

4.2.3 *Evaluation*

Concept Demonstration and Evaluation of Design Activities

Two evaluation sessions were conducted with the same participants as in the design workshops. A brief introduction to the research project and a prototype demonstration from Iteration 1 were conducted. The sketches from the designer workshop were presented and discussed with the participants. The design activities, alongside the concept demonstration, provided insights that were analyzed and categorized by the following recurring themes: **The nature of news consumption**, **Interactive learning/exploration and gamification**, and **Accessibility**.

The nature of news consumption: Considering the affordances provided by MR technology, two participants, one from each workshop, commented on the way they consume news content. Reading news is often an activity that takes place during a short period, and one of the participants noted that they prefer to sit down to read the news rather than stand upright.

Interactive learning/exploration and gamification: Two participants pointed out direct manipulation of content as a means for memory retention. Furthermore, most of the concept drawings done by the participants encompassed some form of direct interaction with the content. In addition, all the participants' concepts involved 3D maps that took advantage of the spatial affordances of MR and HL2. Gamification of the experience was also mentioned in two concept drawings.

Accessibility: Some participants mentioned text-to-speech as an accessibility-enhancing functionality they would have liked. Leveraging the spatial affordance of HL2, as outlined in Section 2.4.1, can make the experience of reading the news article exciting and exploratory; however, too much could lead to strain if the user must walk between components to interact with or read the content.

4.2.4 *Reflection*

Scaling the prototype back generated an opportunity to look at visualizing an article in a MR environment from a less constrained point of view, which was beneficial in both the design activities and the evaluation. The design activities yielded insights into what the participants expected from a news article visualized in a MR environment. Three aspects will be central for the next iteration:

Building further on interactive content: Including more interactive elements was predicted to be important and has thus been in the pipeline since the first iteration. The user evaluations in both Iterations 1 and 2 confirmed this prediction. The design activity and the evaluation further strengthened the notion of including a map as a central component.

Possibility for exploration, employing more of the interaction methods supported by HL2: Regarding interaction methods, the participants were most concerned about isomorphic manipulation. However, it was mentioned that moving around a lot could be strenuous. With the

HL2 system, developers can deploy interaction methods such as gaze and voice commands, enhancing accessibility for people with various disabilities.

Opportunities linked to spatial design: Lastly, the benefits of taking advantage of the spatial nature of AR were emphasized in the design workshop and became a priority for subsequent iterations.

4.3 Iteration 3 – Protype with Interactive Components

Iteration 3 was the first iteration where the components in the prototype were interconnected. Additionally, it was scaled up in fidelity compared to the prototypes from Iterations 1 and 2. The prototypes in iterations three and four were developed using Unity version 2020.3.41, MRTK 2.8, and .NET standard 2.0. To build the components in the prototypes, it was decided to utilize Microsoft's MRTK2 (Microsoft, 2022e). The toolkit contains several prefabs that enable developers to quickly prototype MR applications (Microsoft, 2022e). Additionally, MRTK allows the developer to explore spatial interactions and a variety of user interface components.

The scope for Iteration 3 was *selected* by reviewing the report from the prior iteration, investigations into user requirements, and guidelines for developing accessible MR applications. This phase helped solidify the *design* activities, leading to concrete design decisions implemented in the prototype. Furthermore, these activities collectively inspired the user *evaluation* activities. The results from the evaluation were analyzed and *reflected* upon in a field report (Sviland & Tveranger, 2022c) summarized in this section.

4.3.1 Selection

A review of the prior iteration's field report and a literature review were conducted. The findings from design and evaluation activities gathered during the previous iteration pointed toward the concepts mentioned in Section 4.2.4 as notions to be investigated further. A review of the literature concerning use cases and affordances of MR/AR and HL2 was conducted. The domain knowledge that was investigated was the Microsoft HL2 documentation (Microsoft, 2022b), with an emphasis on user requirements and best design practices for developing accessible AR applications, as well as other efforts at creating guidelines for accessible MR development (Elor & Ward, 2021; Hedvall, 2009; O'Connor et al., 2020; O'Connor et al., 2021). These activities motivated the contents of the design activities and the evaluation process.

4.3.2 Design

The design process for the third iteration was mainly focused on prototyping activity and familiarizing with the different prototyping tools available. Subsequently, moving on to implement the design and functionality grounded in the results from the former iteration. The visual appearance of the prototype is depicted in Figure 11 and is further described in

Table 6. A crucial decision regarding the type of prototyping tool and technology was ahead. Several tools were considered and tested, but Unity was decided to be the primary development tool. Unity was deemed best suited considering its integrations with MRTK and deployment integrations with HL2. A HL2 design system and MRTK component library in Figma were used for rough sketching and design explorations.

Furthermore, familiarizing with the tools also laid the grounds for some design decisions. Knowing the different constraints made it more apparent what would be possible to achieve and what not. For example, early in the familiarization, *Blender* (Blender), a 3D-modelling platform, seemed the most appropriate tool for designing the components. However, MRTK includes prefabricated components that are easy and quick to implement. In addition, several map integrations were investigated before deciding what was to be implemented in the prototype. The following design activity encompassed implementing design and functionality derived from insights from the previous iterations and the literature review.

Figure 11: The prototype per Iteration 3.

Table 6

The anatomy of the prototype by Iteration 3

Dimensions	Definition	Variables
Filtering	Appearance	Five holographic components organized in two levels as a workstation at the eye level of the user. The default size of the composition is approximately 1m x 1.5m. *Text box*: White text on a dark grey back plate. *Progress bar*: A blue line to represent the progress bar and white numbers to depict the progress. *Navigation pane*: A blue, rectangular component with a text area and buttons underneath. The buttons are blue when active. *Map*: Dark blue landmass on a lilac back plate. Areas on the map turn red when mentioned in the article. *Image and image box*: An image placed directly above an empty dark grey box. The sizes of the text box, map, and image are roughly the same.
	Data	*Text box:* Contains the news article with written text. Each text box contains roughly the same amount of text. *Image box:* An image and a placeholder box for image text. *Progress bar*: Contains a counter and a colored bar that increases in length when reading. The counter denotes pages read as well as pages left to read. *Navigation pane*: Contains a short informative text at the top. Underneath is a list of the sub-headlines. *Map*: Contains map markers, where the names of the location act as the marker. *Metadata box*: Containing written information about and images of the people interviewed in the article.
	Functionality	Reading an article more in-depth by exploring additional data related to the article. Understanding the content better with the aid of accessibility-enhancing features.
	Interactivity	*Interaction methods*: Opportunity to use both near- and far interaction to navigate the prototype. *The scene*: The composition is moveable and scalable, but only as a unit. *The text box*: Interactable by clicking back/next on the box. *Navigation pane*: Clickable buttons on the navigation pane for navigating the article.
	Spatial Structure	3D representation of a news article and components related to it. The set-up is calibrated to open at the user's eye level, where the text box is the focal point, and the other components are placed to the side and the map at the bottom. The text box's contents dictate the content of the image box, map, progress bar, and metadata box. The sub-headlines in the navigation pane are highlighted depending on which section of the article is active.
Manifestation	Material	The holograms are projected onto the physical display of the HL2.
	Resolution	The current prototype fidelity is considerably higher than in the preceding iterations. The level of interactivity is not substantially higher than in iteration one. However, more components have been implemented, utilizing more opportunities afforded by displaying an article in a MR environment. The data in the text box is a news article from the media house VG (Verdens Gang), and the data presented on the map mirrors the information in the article. The image text box contains a blank text box.
	Scope	Focus on presenting the article and how context-based images and map information is helpful to the user. In addition, it is important to evaluate whether the added features to aid the reader in staying oriented in the text were successfully implemented.

4.3.3 Evaluation

User Evaluation of Prototype

For the evaluation of the prototype in the third iteration, one of the features being tested was the concept of metadata being adjusted based on the contents of the text box. The other important aspect to be evaluated was the components that were added to keep the reader focused and oriented in the text. Three participants were recruited from the Department of Information Science and Media Studies and were 25 to 28 years of age. One of the participants had dyslexia, while the other two did not report any difficulties related to reading or writing. The participants were students and were interested in new technology. One of the participants was recurring from both Iterations 1 and 2. The evaluation sessions were all conducted at the UiB Campus.

To evaluate the prototype, the participants were tasked to read through the article and explore the prototype while thinking out loud. The sessions were concluded with interviews (Appendix B). Before moving into the main task, and similarly to Iteration 1, the participants got time to warm up by exploring the hand interaction examples in the MRTK examples hub. The sessions were monitored by streaming the feed from the HL2 to a laptop, enabling the researchers to assist the participants if need be. After completing the practical tasks, the participants were interviewed about their experiences. The interview was semi-structured with talking points related to the specifics of the components as well as the experience of using the body to navigate the system. Three recurring themes were detected during analysis: **Legibility**, **Interactivity**, **Orientation**, **Personalization**, and **Issues related to interacting with HL2**.

Legibility: Both during the tasks and during the interviews, observations and comments regarding legibility came up. One participant pointed out that they wanted the possibility to see all the components simultaneously and had to scale down the composition to cater to this need. However, scaling the composition down rendered the text in the text box too small. The same participant commented on the spacing between the lines.

Interactivity: More interactivity was a subject that came up in each session. The participants wanted to interact more with the map and noted that they missed the opportunity to zoom in to get more information about the countries in the text. The same sentiment went for the content of the metadata box: the participants wished for an opportunity to explore more. One participant felt that they were “closed off” by the prototype when unable to perform internet searches. Additionally, all three participants mentioned that they enjoyed the immersive and interactive experience of reading a news article in a MR environment. One participant stated that it was easier to remember the content and stay focused because of its engaging nature.

Orientation: One participant stated that a map in this context could be significant for keeping track of where you are in the world, thus keeping the reader oriented in the article. The progress bar was also mentioned as a constructive component; however, it could be improved to be more helpful.

As the map was partially outside of the FOV, changes frequently occurred in the map without the participants noticing. Two participants noted that it would help them stay focused and oriented if they were notified of the changes. In addition, this would be an overall nice feature to have regarding subtle changes in the content of the components that were not in the direct line of view.

Personalization: Some of the issues, as mentioned earlier, could be offset by implementing functionality to customize the content. Two participants noted that adding functionality for adjusting text size and line and text spacing would be beneficial.

Issues related to interacting with HL2: Two out of three participants were first-time users, and challenges from Iteration 1 regarding interacting with the HL2 system were prominent in this iteration, too. In the preliminary study, findings pointed out that the participants struggled with scrolling as an interaction method. This led to the implementation of clickable buttons to navigate the article, which could be clicked on using both near and far interaction. One participant noted that they would have liked to navigate the text boxes by swiping instead of clicking. It was added that leveraging the pinch interaction would resemble turning pages in a book.

4.3.4 Reflection

Moving toward a prototype that leveraged more of the affordances provided by the HL2 system aided in addressing some of the issues raised in the prior evaluations. Working around some of the limitations that led to difficulties in interacting with the system led to the evaluation being conducted with less "noise" that could clutter the results. Furthermore, adding additional components to the prototype was beneficial in several ways. Doing so led to the opportunity to evaluate the components in a context of use and in context to other components. Furthermore, implementing more components facilitated evaluating whether this led to the participant being overly stimulated or whether it was perceived as acceptable. Some concrete design issues related to accessibility were decided to be addressed in the final iteration. This encompassed legibility, interaction, orientation, and interactivity. Furthermore, various opportunities for personalization were to be investigated as well.

Legibility: Enhancing the legibility in the text box was a high priority for the next iteration, as it would entail minor changes that were easy to implement. Added spacing between lines or highlighting and underlining text has proved to be powerful tools in supporting text comprehension

(Stearns et al., 2018; Watson & Wallace, 2021) for people with and without dyslexia (Watson & Wallace, 2021).

Interaction: Using the built-in hand gestures appeared to be something all the participants had issues with, even though they had interacted with the HL2 for a second time. At one point in a session, one of the participants wanted to avoid rotating and moving the scene, causing them to accept a very inconvenient placement. Because of this, it was suggested that it might be beneficial to implement a reset button so that the scene resets to its original position to avoid causing additional strain to the reader.

Orientation and interactivity: A more interactive map was a feature that was attempted to be addressed more significantly in Iteration 3. Some of the features that were scheduled to be a part of the release had to be left out because of time constraints. The progress bar was another component suitable for being more interactive and became a high priority in the next iteration. Furthermore, being notified of changes by being "nudged" in the right direction is a feature that can enhance the feeling of being oriented in the text. Small changes in the metadata box or map, such as highlighting information, can significantly impact the perceived affordances of the scene.

Personalization: An important finding pointed toward being able to scale the scene up or down or move it around as a necessary functionality to implement. To be able to modify the composition itself was functionality worth putting resources into to enhance ergonomics and legibility.

4.4 Iteration 4 – Final Iteration

For the last iteration, the prototype did not increase much in fidelity. However, new functionality to enhance accessibility was implemented. The scope for the previous iteration was *selected*, as in Iterations 2 and 3, based on the results from the field report and by conducting a literature review. The *design activities* were focused on formalizing the results from Iteration 3 into concrete design decisions and then implementing the design. Seven participants *evaluated* the prototype. This was done by using a task-based evaluation followed by an interview. The evaluation was analyzed, *reflected* upon, and summarized in this section.

4.4.1 Selection

The findings and knowledge acquired from the report from Iteration 3 solidified some of the assumptions and highlighted some new aspects. Design decisions concerning the different components and user requirements were already in the pipeline for the next development phase. However, the findings also directed the focus toward the notion of personalization as well as a concrete aspect of orientation: the need to be nudged or notified when changes in the content occur.

For this iteration, as well as the prior, the MS documentation (Microsoft) was crucial in the attempt to design an application following best practices. The MS documentation was used as a reference throughout the design process. Furthermore, this literature review focused on examples of MR and VR as embodied experiences for enhanced engagement (Handosa et al., 2018; Koebel & Agotai, 2020; Lindgren et al., 2016). The findings from the field report and the literature review motivated the design decisions and informed the activities involved in the evaluation.

4.4.2 Design

The design process comprised two activities, a design workshop conducted by the researchers and a development sprint where the prototype was further developed.

Design Workshop

The design workshop, depicted in Figure 12, was conducted together with the co-developer of the prototype. The workshop consisted of two sprints, each centered around one of the components. The components chosen to be the focus of the sprint were the progress bar and the map. These components were selected because they are meant to support and improve upon notions of orientation and overview. Moreover, they connect components, strengthen the sense of overall interconnection in the prototype, and encompass opportunities for added interactivity. Lastly, further developing these components sets the grounds to further leverage the affordances of MR and HL2.

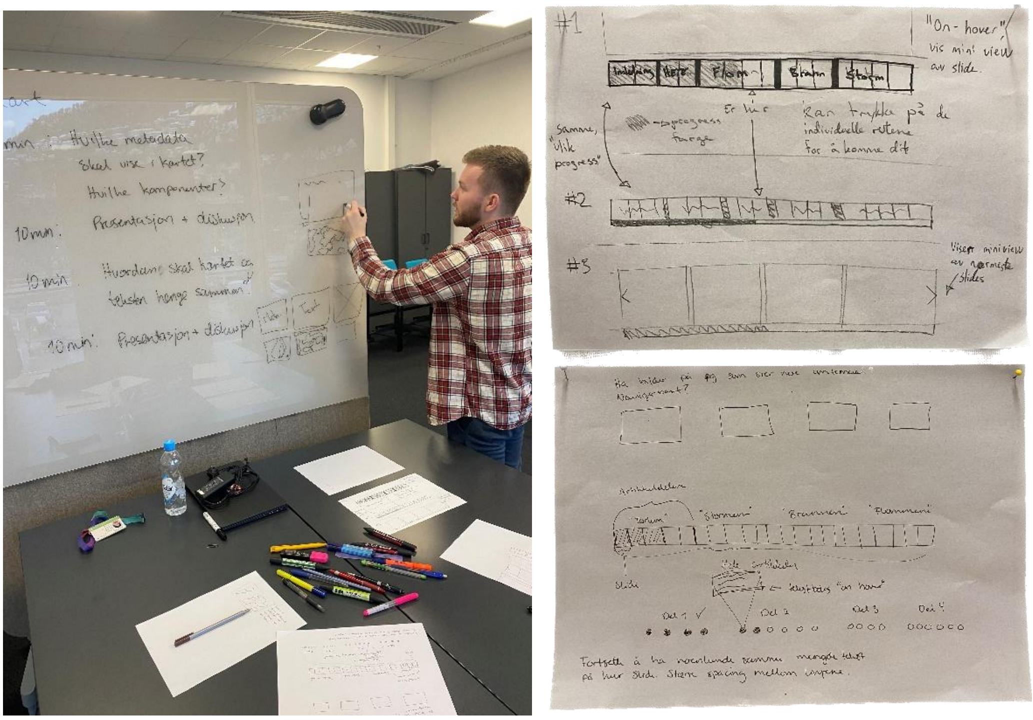

Figure 12: Design workshop conducted by both prototype developers.

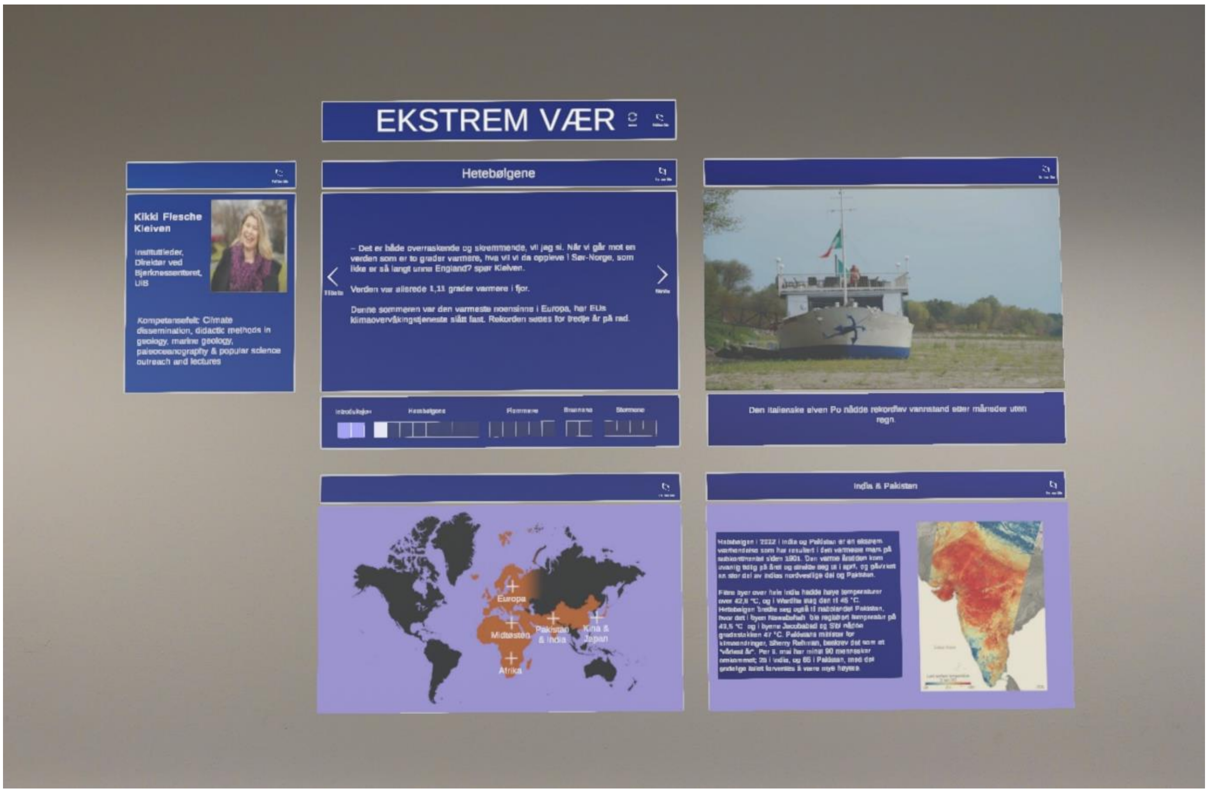

Figure 13: Screen capture from HL2 of the final iteration of the prototype

Prototyping: Development Sprint

The prototype's visual appearance is depicted in Figure 13, and a description and technical specifications by the end of the design activities in Iteration 4 are summarized in Table 7.

Table 7

The anatomy of the prototype by Iteration 4

Dimensions	Definition	Variables
Filtering	Appearance	Six holographic components organized in two levels mimicking a workstation, placed at eye level of the user. The default size of the composition is approximately 1m x 1.5m. The size of the text box, map, and image are about the same, and the metadata boxes are smaller. All components have a title bar at the top. *Title bar*: A blue bar at the top of the scene containing a headline and two buttons. *Text box*: a blue rectangle with white typography and two buttons for navigation. *Progress bar*: A blue rectangular bar with white text and smaller boxes that change color depending on their state. *Image box*: A rectangular image with a white image text on a blue back plate connected to it. *Map*: A lilac rectangular back plate showcasing a world map. Areas on the map are highlighted in different colors depending on which sub-section of the article is being read. *Map metadata*: Slightly smaller than the text box, map, and image. The component comprises a box with white typography and an image. *Text metadata*: The smallest box in the scene. This component contains white typography on a blue back plate next to an image.

	Data	*Text box*: Contains the news article. Each text box contains roughly the same amount of written text. *Image box*: An image and a box containing textual data about the image. *Progress bar*: Contains written text denoting sub-headlines in the article and small boxes representing each news article page. The color of the boxes denotes pages read, which one is active, and which pages are left to be read. *Map*: Map with map markers, where the names of the location and a button act as the actual marker. *Text metadata box*: Contains written information about the people interviewed in the article and their images. Map metadata: Contains written information about locations on the map and context-supporting images.
	Functionality	Reading an article in-depth by exploring additional data related to the article. Understanding the content better with the aid of accessibility-enhancing features.
	Interactivity	*Interaction methods*: The users had the opportunity to use both near and far interaction to navigate the prototype; however, only far interaction to navigate the text box. *The scene*: The composition is moveable and scalable, and it is possible to adjust the components' placements and sizes individually. Additionally, functionality for resetting the scene and for the scene to follow the reader around has been added. *Progress bar*: The boxes are clickable, and if hovered over, a thumbnail of the page is visualized.
	Spatial Structure	3D/holographic representation of a news article and components related to it. The setup is calibrated to open at the eye level of the user. The text box is the focal point, the other components are placed to the side, and the map is at the bottom. The content of the text box dictates the content of the image box, map, and text metadata box. The content of the map metadata box is dictated by which area of the map is clicked.
Manifestation	Material	The holograms are projected onto the physical display of the HL2.
	Resolution	The prototype's fidelity is higher than in Iteration 3. The level of interactivity is not considerably greater than in the prior iteration. However, more components have been implemented, exploiting more of the opportunities afforded by displaying an article in a MR environment. The data in the text box is the same as in the prior iteration, but more visual content has been added. The image text box contains text retrieved from the source the image was retrieved from.
	Scope	Focus on presenting the article and how the context-based images and map information are helpful to the user. In addition, it is important to evaluate whether the added features to aid the reader in staying oriented in the text were successfully implemented. For this iteration, interactivity for engagement is also a focus.

4.4.3 Evaluation

User Evaluations and Interviews

The final evaluation consisted of a user evaluation of the prototype, followed by interviews and discussions (Appendix C). Analyzing the findings from Iteration 3 provided results that pointed toward the need to focus more on aspects such as legibility, interactivity, orientation, and the possibility for added personalization, which was implemented in the prototype to varying degrees.

Six participants were recruited from the Department of Information Science and Media Studies, and one from a referral. The participants were 22 to 28 years of age. One of the participants had dyslexia, while the other six did not report any difficulties related to reading or writing. All the participants, except for one, were students interested in new technology. One of the participants was recurring from all the preceding iterations, and one recurring from the second iteration only. The evaluation sessions were conducted at the UiB Campus, each lasting approximately an hour.

To evaluate the prototype, the participants were tasked to read through the article in the prototype while *thinking aloud*. The sessions were concluded with a semi-structured interview and a discussion. As in the previous iterations, the participants got time to familiarize themselves with the MRTK examples hub. For this iteration, the tutorial tasks mainly focused on the far interaction (Figure 4) and using this to rotate components. Far interaction was emphasized because a bug in the prototype rendered it impossible to use near interaction to navigate the text box. Furthermore, seeing that the participants encountered problems when rotating components during the previous evaluation, it was decided that this was worth spending some time on. Additionally, this prototype release provided the possibility for moving components independently from each other. This addressed the issues regarding rotation and would hopefully lead to the participants being able to rotate the components more easily. The sessions were monitored by streaming the feed from the HL2 to a laptop.

The interviews were semi-structured, with talking points related to the components and the experience of using the body to navigate the system. The interviews were concluded with a self-assessment task. In this task, the participants were asked to give themselves a score corresponding to the degree to which they thought they mastered this way of reading a news article and whether they thought that this way of interacting with an interface led to enhanced text comprehension. Four main topics, containing multiple sub-themes, were discovered during the thematic analysis of the evaluations: notions of **Accessibility**, **Orientation**, and **Personalization**.

Accessibility

Several notions of challenges related to accessibility as well as opportunities to enhance accessibility, were discovered during evaluations. Key themes that were identified related to this topic were *interactivity*, *ergonomics*, and various challenges related to *legibility*.

Interactivity and interaction methods: Four out of seven participants noted that actively engaging with the content led to better text comprehension, and four participants thought it was suitable for engagement and immersiveness. Three participants wanted more interactivity and looked actively for interactive elements in the prototype.

The steep learning curve related to hand gestures in HL2 heavily impacted the ease of use. This was perceived by most of the participants to cause some hindrance in exploring the prototype and understanding the content of the article. However, the participants noted that getting used to it did not take a long time, which pointed toward learning to use the HL2 system, and the prototype was not very challenging overall. When reaching a higher level of proficiency using gesture-based navigation, the participants could give more nuanced feedback on the prototype. The participants described that the experience was engaging and exciting. Three participants accredited some of the ease of use and engagement to the notion of feeling present and aware of the physical situation around them while interacting with virtual content. Also related to the ease of use, the size and weight of the device were brought up. One participant mentioned explicitly that they did not imagine leisurely reading the news and drinking coffee while wearing the HMD.

Regarding interacting with the prototype's content, participants noted that navigating the text box from afar was straightforward. Furthermore, managing the layout of the scene was made more accessible, which in turn led most of the participants to explore different configurations by themselves. The progress bar was mentioned as helpful in quickly navigating to other sections of the news article. A limitation to this component, remarked on by some participants, was that the thumbnails that appeared when they hovered over it could have been larger to enhance legibility. Scaling up the thumbnail would render it a better mode of navigation, as noted by a participant. Another limitation of the design was that once one or more of the components were layered directly on top of each other, it was difficult to navigate between them. Additionally, the components in the prototype were not sufficiently context-aware. This enabled the participants to place components through walls and tables and were thus unable to interact with them.

Being able to sit back and at a distance was mentioned as a positive when interacting with both the HL 2 system and the prototype. One participant mentioned that utilizing other interaction and navigation methods than scrolling was a positive. Another participant said that gaze interaction would be interesting to explore. However, as mentioned in the evaluations of the prior iterations, there were negative comments on interacting using the HL2 hand gestures. As in the earlier iterations, there were challenges with the pinch gesture. The challenges were associated with the need to exaggerate the gestures sufficiently for the HL2 sensors, outlined in Section 2.4.1, to detect them. Not exaggerating the gestures adequately rendered the participants unable to select objects and caused frustration.

Ergonomics: Four participants reported that navigating the prototype from afar was a comfortable experience. Being able to modify the layout of the components was also noted as a positive for the experience because it made it more ergonomic. Nonetheless, a few factors impacted ergonomics in the opposite direction. Using one's arms to such an extent was a bit tiring, but only one participant mentioned this. Furthermore, the users frequently moved their gaze or head to look at the other components while reading the text to obtain additional information. This was reported to feel a bit unfamiliar. Likewise, the limited FOV also impacted the need to move their necks and heads to obtain all the information, leading to some strain.

Legibility - cognitive overload and focus: The news article in the main text box and the image text were acceptably sized. In addition, the amount of text on each slide, the color of the text, and the box's background color were perceived as adequate. However, the text size of the map metadata, as well as of the text metadata, was commented on as poor by all participants except for one. The legibility of the images that depicted graphs was also inadequate. Most of the participants noted that there was too much textual information in the map metadata box. Two participants stated that the text metadata would be more legible if the text were segmented as a list of bullet points. To mitigate the small text and to otherwise investigate the components, it was observed that the participants actively pulled the components closer and then put them back into the layout. Clicking on or hovering over a particular component to bring it front and center of the layout was proposed to counter issues with illegible text and images and relieve some strain. One participant did, however, note that they preferred being able to manually pull components back and forth instead of the aforementioned solution.

As well as impacting legibility, the amount of text in both metadata boxes affected the participants' ability to stay focused. Furthermore, the limited FOV played a central role in how the participants perceived the information and kept their focus. A downside frequently commented on regarding the limited FOV was that the participants did not know precisely when the contents of the map and metadata boxes changed. One participant was very annoyed at the restricted FOV, and others noted that they lost their focus and flow because of it.

Orientation

One way of enhancing legibility to counter cognitive overload is to keep the user oriented. Having an overview of the article was noted as beneficial by the participants. The progress bar was mentioned as a component that contributed to this. In addition, notions of structure, context support, and ambient notifications were prominent themes. Furthermore, the map and metadata boxes added to the impression of being oriented in that they supported the article.

Additionally, the possibility of having every component laid out in the room as a workstation was noted as a positive. Participants reported that having everything in the vicinity prompted them to interact with components, stating that if they had been hidden, they might not have. Almost all the participants modified the layout to make all the components visible in the FOV. One participant argued, however, that it could be beneficial to choose which components were visible and minimize others for a more straightforward layout. One participant also mentioned that the functionality in the map to reveal the metadata on-click was positive.

Context supporting components and structure: The components that supported the content were overall well perceived, even though not one component stood out. It was noted that the map, progress bar, and metadata added context to the article text, however, to varying degrees depending on which participants were asked. Nevertheless, because the map metadata box contained too much information, it obfuscated its purpose as a context-supporting component. In turn, this led to the participants not reading the text thoroughly. One participant noted that complex or unfamiliar words, such as the content in the text metadata box, should be clickable to examine them further for additional context. Two participants mentioned that they wanted alternatives to the written text, such as a text-to-speech functionality, and one mentioned video as an alternative or addition. Additionally, if the thumbnails in the progress bar were improved, i.e., if they provided more information about the article page or which part of the article it belonged to, it would make navigating the article easier, one participant noted.

The layout and navigation of the prototype are organized horizontally, whereas, in a typical digital news article, the text and images are intertwined and organized on a vertical layout. This was assumed to cause some confusion. However, the information hierarchy and structure of the layout were mentioned as supporting the context and thus providing the participants with a feeling of being oriented. Additionally, being able to modify the layout themselves gave the participants a choice to decide what was more important, two participants noted.

System feedback, ambient notifications, and fail-safes: Some of the built-in system feedback in the HL2 system was mentioned as useful, such as the beam that radiates from the user's hand when pointing and the highlight surrounding objects that are being pointed towards. In addition, it was mentioned that it could be beneficial to highlight the geolocations in the text box or to highlight one country at a time on the map. The participants remarked on the issue of not noticing changes in the components' contents and accredited it to the restricted FOV. Two participants noted that a notification system could be implemented to subtly nudge the user toward the changed content to mitigate this.

The visual appeal of the components was mentioned as something that could have been more aesthetically pleasing to some of the participants. The design of the top bars, which enable interaction with each component individually, is a trade-off to make the interaction easier. The participants accepted this trade-off.

Personalization

Being able to modify the layout was broadly accepted as a positive functionality in the prototype. Almost all the participants used some time to alter the layout in a way that formed a semicircle in front of them. The motivation behind this particular layout was the need to be able to bring all the components into the FOV. By doing so, they achieved two things: easing strain on the neck and enhancing the sense of an overview. Being able to modify the layout rendered it up to the participants themselves to dictate the importance of each component added to the sense of personalization. Additionally, having the option to add accessibility-enhancing features, such as text size and line spacing, was mentioned by some participants.

4.4.4 Reflection

The topics discovered during the thematic analysis of the data gathered supported some initial claims that were materialized in the design decisions of the prototype. Examples of this were the positive impact of perceived overview, added interactivity for engagement, added opportunities for personalization, and the effect of difficulties related to the HL2 hand gestures and the limited FOV. Additionally, it was observed that to which degree a participant found a component helpful or not varied among the participants. The results point toward leveraging affordances, such as utilizing HL2's different methods of interaction were engaging and beneficial for accessibility. Furthermore, HL2s spatial nature and its context awareness added to the sense of being oriented in the article.

Navigating the prototype was significantly more manageable than in the previous evaluation sessions. The participants seemed overall more confident in exploring the prototype, which could be attributed to them being more adept in interacting with the HL2 system and the improved prototype interface. The various components were reported to be easy to use and helpful in staying oriented in the news article. However, the substantial discrepancy in which component was most favored amongst the participants points out that not one type of component, or visual cue, is the best fit for every need. Moreover, being able to modify the layout allowed the participants to dictate the importance of each component. The possibility to personalize the tools and the layout had an overall positive impact on the user experience.

5 Discussion

Through building a prototype, this research project has addressed challenges and opportunities to enhance the accessibility of digital news articles presented in a MR environment. This was done by investigating the affordances of a specific MR technology through the prototype. Insight and data gathered through user evaluation were translated into concrete design decisions and implemented in the prototype for further development. While previous research has focused on use cases of MR in an educational setting, this project has looked at MR in a leisurely environment, i.e., reading news. The results indicate that ease of use, interactivity, orientation, and personalization impact accessibility. In turn, accessible MR applications may be achieved by leveraging the affordances provided by MR technology. In this chapter, the results from the user evaluations will be discussed and seen in context to existing studies of accessibility in digital written text, evidence of accessibility afforded by MR systems, and guidelines and standards for developing accessible MR applications. Before moving on to the discussion, a revisit to the research question is provided: *In which ways can the affordances provided by wearable MR technology enhance the accessibility of digital news articles?*

5.1 Leveraging the affordances provided by MR

This thesis aims to investigate whether leveraging affordances provided by MR technology, namely HL2, can enhance accessibility in news articles. The technology in question was explored through embodiment as a lens. Furthermore, embodiment involves contextualized technology and interactions and indicates a participative status. The results from the user evaluations indicate that interacting with objects, and more notably, through direct manipulation, will enhance engagement and notions of accessibility. These results, in turn, resonate with Dourish's sentiment that reducing the complexity of interactions renders computation more accessible: "[…] because we have highly developed skills for physical interaction with objects in the world – skills of exploring, sensing, assessing, manipulating, and navigating – we can make interaction easier by building interfaces that exploit these skills" (Dourish, 2001, p. 206). By using the different interaction methods available or leveraging spatiality for added context, users of MR systems are offered a more direct and contextualized form of interaction (Zhang et al., 2023), enabling a broader range of skills to be used. The following sections are exemplifications of challenges and opportunities to leverage the affordances provided by MR.

5.1.1 Ease of Use

How quickly the participants familiarized themselves with the HL2 system, e.g., its *ease of use*, impacted the results significantly and perhaps more so than expected. The findings in this project are in line with the results of related studies such as John et al. (2022), Balani and Tümler (2021), and Stearns et al. (2018), where there is an emphasis on letting users familiarize themselves with the MR system in question before the evaluation starts. Building on the findings as mentioned above, the decision to allocate time for the participants to get acquainted with hand interactions through the MRTK examples hub was already implemented in Iteration 1. Additionally, the participants involved in more than one evaluation showed significant improvements in navigating the system and the prototype. The participants' skills in using the system were not something that was measured in itself. However, their competence directly correlated to the degree to which they felt comfortable exploring the prototype without guidance. Moreover, there was a significant difference in skill between participants with an affinity for technological innovation and those without.

Even though the overall attitude toward the prototype and the MR system was positive, it was difficult for the participants to envision using this device for leisurely everyday activities. This is also impactful for adapting technology (Lafargue, 2018; Oni, 2013). Consequently, this is where this study differs from similar ones. The majority of the related studies make inquiries about learning situated in educational institutions or industrial settings. Furthermore, the physical manifestation of the device itself can also implicate a broader use and, thus, the adaptation of the technology. Even though the device is much lighter and less unwieldy than most VR systems, this issue is still prominent to such a degree that it would not be suitable to use while on the bus or by the kitchen table, drinking coffee.

5.1.2 Interactivity

Participants generally reported that exploration through interaction positively impacted their experience and wanted more interactive components. These findings are comparable to the results in studies by John et al. (2022), which showcase student engagement and increased memory retention when aided by an MR system, and Vi et al. (2019), where interactions with 3D models are proposed as a way to alleviate the cognitive load. The interactions were, however, implicated by to which degree the participant felt comfortable with the interaction methods, as discussed in the previous paragraph.

5.1.3 Orientation

In line with Gaver's (1991) notion that perceptible affordances lead to action, the overview of the various components gave the participants an indication of the prototype's features and capabilities. Furthermore, this was accomplished by leveraging the spatial affordance of HL2. This corresponds to the guidelines provided by Vi et al. (2019), where they urge developers to leverage the spatial nature of MR to enhance comfort and minimize the user's amount of conscious thinking. However, the limited FOV of HL2 made displaying the components challenging. This did, in turn, lead to some discomfort. On the other hand, the limited FOV enabled the participants to focus only on what they thought was important, preventing errors as well as cognitive overload. These findings align with the principles of *Progressive Disclosure*, where the user is presented with only a few options, but a more extensive set is offered upon request (Nielsen, 2006).

As established in studies on dyslexia and reading comprehension, sensory cues are often lost in digitally written texts (Cavalli et al., 2019; Mangen et al., 2019). To mitigate this, various components and features were implemented. Furthermore, the components can serve as methods to keep users oriented within the news article. The use of various sensory cues is discussed by Cavalli et al. (2019), Schnotz (2002), and Watson and Wallace (2021) as beneficial not only for people with dyslexia. In line with these studies, the results from evaluating the prototypes suggest that the context-supporting components helped determine the participant's progress in the article and remembering what they had read.

5.1.4 Personalization

Flexibility in and customization of the environment and interactions are important factors for improving accessibility for a wide range of users, as discussed by O'Connor et al. (2020) and Vi et al. (2019). Not one specific component in the prototype was considered the most important. This insight points to the notion that being able to modify the layout to the user's preference is valuable for the experience. By modifying the layout, the individual participant influenced the information hierarchy, deciding which components were most important to them. Moreover, adjusting the components adapted the layout to each participant's ergonomic needs.

As decided in Iteration 3, a button for resetting the scene was implemented. This functionality became even more critical after implementing the functionality to modify the scene and move each component independently. Accordingly, it became evident that there was a need to reset the layout to its default state. Vi et al. (2019) recommend features such as this to relieve users of anxiety when they have made a mistake and to stimulate further exploration of the application. In line with common usability heuristics in HCI (Molich & Nielsen, 1990), functionality was implemented to prevent users from moving components without meaning to do so. A top bar was implemented so the user had to grab a specific part of the component to move it around.

5.2 Design Implications

To address some of the issues related to accessibility, several adjustments were planned and partially sketched out but not implemented in the prototype. The additional features encompass multiple possibilities to personalize content and to utilize the affordances of HL2 further. The features are summarized in Table 8, depicted by the type of accessibility enhancement, functionality, and interaction method, if applicable.

Table 8

Feature overview of the accessibility menu.

Type of accessibility enhancement	Definition	Interaction method	Feature functionality
Legibility	Text size	Hand/Gaze	Adjust text size for one word or the entire text.
	Inter-letter, inter-word, and inter-sentence spacing	N/A	Adjust inter-letter, inter-word, and inter-sentence spacing.
	Text simplifier	Hand/Gaze/Speech	Language model to automatically shorten or simplify the text, either by selecting specific text snippets or by default.
	Color profile	N/A	Change the color scheme based on preference, needs, and physical environment.
Orientation	Text underline	Hand/Gaze	Underlining sentences by pointing or looking at them.
	Word highlight	Hand/Gaze	Highlighting words by pointing or looking at them over some time.
General accessibility	Text-to-speech	Hand/Gaze/Speech	Read the article out loud when selected or by default.
	(Physical) Environmental awareness	N/A	Applying constraints to the components to prevent unintentionally placing them under tables and behind walls.
	Component awareness	N/A	Applying constraints to the components to prevent them from layering on top of each other or other virtual content.

Furthermore, relying on other affordances of the HL2, such as voice commands and gaze interaction, is beneficial for the user experience. Utilizing more than just hand gestures can alleviate strain on the neck and body and render it accessible to users that cannot use their hands to navigate the prototype. Lastly, adding an ambient notification system for notifying users about change can increase the sense of orientation.

6 Challenges, Limitations, and Recommendations

The RtD-process conducted in this study revealed various limitations to this body of work but also opportunities for future work. In this chapter, challenges regarding the sampling of participants and conducting user evaluations will be addressed. The hardware and technology challenges have already been addressed in Section 2.4.1.

6.1 Challenges and Limitations

6.1.1 Sampling

Conducting workshops with participants with the same occupation or background involves several risks. One of them is that their ideas may influence each other's concepts, leading to a homogenous result without much diversity. This is one of the reasons behind the decision to source participants from different age groups. However, the groups of participants could have been mixed to overcome this bias (Baxter et al., 2015). Considering this, both groups produced similar concepts and ideas, leading to the assumption that age might have less to do with the outcome than first assumed. Instead, their shared background and similarities in their fields of interest might substantially influence the result.

Convenience sampling can lead to an unvaried pool of participants that can, in turn, result in inaccurate data (Baxter et al., 2015). By recruiting participants through the Department of Information Science and Media Studies, the author of this study and the prototype co-developer ran this risk. Another limitation implied when sampling conveniently is that the researcher already has a relationship with the participant. This could lead to the participant being overly positive toward the artifact that is being evaluated. Furthermore, participants being overly helpful and thinking this will lead to *correct* or *good* results is within psychology called *demand characteristics* (Brown et al., 2011). On the one hand, helpful and eager participants are essential for a study to succeed; however, user compliments toward the system must not be interpreted directly to success (Brown et al., 2011).

6.1.2 Procedure

In addition to the relationship between participant and researcher, the setting in which the evaluation occurs may affect the results. For example, choosing a setting with no place to move around, constricting the participant's ability to interact appropriately with the prototype, or a noisy environment can implicate outcomes. Furthermore, how the evaluation is framed by the researchers and inconsistencies in the evaluated artifact may implicate the results as well. A flaw in the design became particularly noticeable during the use case tasks in Iteration 4 when the participants interacted with the contents of the metadata boxes. The contents of the metadata boxes should have been more thought through. This led to the participants reporting that they were overwhelmed by the amount of text. Seeing that this design flaw took much of the participant's focus away could unfavorably influence the evaluation and, thus, the results. These challenges were addressed, or can be addressed in the future by:

1. Following a strict schema for selecting and preparing the location for the evaluation: Considering that most participants did not have any prior experience using MR HMDs, it was decided early on to conduct the user evaluations in private and quiet rooms. This decision was made to reduce the participants' feelings of discomfort or awkwardness when exploring the prototype. Even though a quiet room is not a "natural" environment to read your daily news, being uncomfortable may have worsened the evaluation and the results.
2. Testing and setting up the technical equipment in apt time before the participant arrived to avoid unwanted situations such as the HL2 running out of battery or issues with the stream from the HL2 to the researcher's laptop. The issues mentioned above were experienced first-hand in the formative testing, leading to valuable lessons. Notably, not having a stream set up made it difficult to successfully guide participants through the tasks and assist them when they encountered difficulties. This was accounted for in the subsequent iterations but may have affected the results of Iteration 1.
3. Alternating roles amongst the researchers: Switching between who was *lead* and *technical* gave an early insight into both researchers' strengths and weaknesses. In turn, this enabled a more nuanced view of how the evaluation was conducted and how to improve upon it.
4. Considering the anatomy of the prototype to a more extensive degree before deployment: being more mindful of the filtering dimensions might have led to less cluttered results. In this project's case, the information density should have been re-evaluated.

6.2 Recommendations

Further potential to enhance accessibility, new ways for news to be presented in a MR environment, and ways to leverage the affordances of MR further have manifested throughout the four iterations of the RtD process. This thesis investigated only one out of numerous impairments. Seeing that MR and AR technologies will continue to grow in popularity, the number of users, and the variation of capabilities amongst them, will continue to increase also. In the context of news consumption, making news more accessible to people with varying degrees of disabilities will remain an important societal issue. MR technology has the opportunity to be integrated with assistive technology to accomplish several tasks, which should be investigated further. Further research into new ways of utilizing bodily input to interact with MR technology is thus highly recommended.

7 Conclusion

This RtD-project explored how embodied technologies, such as MR HMDs, can assist when reading and understanding digital news content. The research question was as follows:
In which ways can the affordances provided by wearable MR technology enhance the accessibility of digital news articles?

The prototype was developed and evaluated iteratively in participation with users. With each iteration, the prototype's fidelity evolved. Different filtering and manifestations of the prototype throughout the process facilitated different perspectives on the concept of news presented in a MR environment. The results indicate that including visual cues that take advantage of spatiality and the various interaction methods of MR technology can enhance accessibility for people with and without dyslexia. This can be attributed to the fact that MR technology offers the user a more comprehensive range of skills to be applied when interacting with content. This entails direct manipulation to engage spatially and in real-time with content using hand-based gestures, voice commands, and eye gaze, i.e., utilizing the knowledge we already have about the affordances of the world.

However, conducting research involving new and emerging technology poses several challenges. Introducing a system to novice users is challenging in and of itself, and the stakes are further raised when introducing new modes of interaction. Considering this, it was, in some cases, challenging to differentiate between whether the user had difficulties with the HL2 system or the prototype. Users reporting having an affinity for technology showed more independence and efficiency when interacting with the prototype. The age of the participants did not seem to influence this. The users' proficiency when interacting with the HL2 and the prototype was not in the scope of this thesis. However, this should be further investigated as ease of use directly correlates to how fast a population is willing to adopt new technology. This is, in turn, important to investigate if users are to switch out their laptops, phones, or tablets to MR HMDs to consume news content or other media in the near future.

This research project has disclosed how the affordances of MR technology can implicate and enhance accessibility in news articles by:

1. Enabling the user to engage with content by directly manipulating it in real-time.
2. Utilizing the spatial nature of MR to modify the layout and cater to different ergonomic needs.
3. Contextualized objects support focus and keep the user oriented in the text.

This may have the potential to be built upon to support the further construction of accessibility guidelines for developing MR applications. Additionally, visual cues for context support and orientation in a written text may enhance accessibility for people both with and without dyslexia and should thus be further investigated.

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Appendix A Interview Guide for Iteration 1

PART 1 – Background

1. Age
2. Occupation
3. Interests - are you generally interested in new technology?
4. Have you tried AR/VR technology before?
5. What relationship do you have with news content? (E.g., read every day, not at all, paper/digital, which format)

*The participant reads a news article from NRK regarding the movie *The World's Worst Person**

Questions related to the article

1. Do you have any immediate thoughts after reading the article?
2. What did you get out of this article?
3. Have you seen the world's worst person?
    a. Do you intend to see it?
4. Did you notice/use the map at the bottom of the article?
5. What does the map contribute to this article for you?
6. How do you read news articles (such as this one) with a lot of geographical information?
    a. If you don't know much about the geography (in the article)?
    b. If you know a lot about geography (in the article)?
7. How much of the geography in the article do you remember?
8. Do you use the map in the article or look up map information outside of it?

PART 2 – Practical part of user evaluation
The participant gets to familiarize themselves with MRTK Examples Hub and then test the prototype

PART 3 – Interview regarding the user experience

1. How did you experience this way of reading an article?
2. Do you have any immediate negative or positive thoughts about the experience?
3. How did the navigation work for you?
4. How was this (reading through HL2) experience compared to the first?
    a. Better/worse?
    b. Easier/heavier?
5. Which improvements are needed for you to start reading articles in this way?
6. Do you have anything else to add?

Appendix B Interview Guide for Iteration 3

PART 1 – Background

1. Age
2. Occupation

Questions related to Dyslexia:

1. Do you use aids when you read digital texts or articles?
2. Do you find it challenging to stay focused when you read digital texts?
    a. If yes: do you know why you find it challenging to stay focused?
    b. How do you stay focused throughout a (long) article?

PART 2 – Practical part of user evaluation
The participant gets to familiarize themselves with MRTK Examples Hub and then test the prototype

PART 3 – Interview regarding the user experience

Experience when reading

1. What do you think about the legibility?
2. What do you think about the amount of text in each text box?
3. Did this way of reading an article work for you?
    a. If yes/no: Why?
4. What would you say worked **better** here than if you had read an article as you normally would?
5. What would you say did **not work** here compared to if you had read an article as you normally would?

Navigation and UI elements

Navigation panel:
1. Did you use it?
    a. If yes: was this intuitive?
    b. If not: why not?
2. What was your preferred mode of navigation? (Did you use the navigation panel or the next/back buttons the most?)

Progress bar:

1. Did you notice it?
    a. If yes: Do you have any thoughts on this?

Appendix C Interview Guide for Iteration 4

PART 1 – Background

1. Age
2. Occupation
3. Knowledge of AR/VR
4. Relation to news

PART 2 – Practical part of user evaluation
The participant gets to familiarize themselves with MRTK Examples Hub, followed by a walk-through of the prototype

Tasks (Think out loud)

1. Read the article while exploring the prototype.
2. The participant is asked to modify the layout.
    a. The participant is asked to explain their choices.
    b. The researchers show additional solutions for the layout.
3. Go through each component (text box + metadata, progress bar, map + metadata, image).
    a. Rate the importance of the components based on how much they impacted your experience and understanding of the text?
        i. Why did you come to this conclusion?
    b. Is there something you miss when reading?
        i. Could something specific have helped the reading comprehension/experience?
        ii. Is something redundant? Was there something that you didn't use?

PART 3 – Discussion

1. Self-assessment/self-efficacy:
    a. Did you feel that you mastered this way of reading an article? (scale 1-5)
    b. To what extent do you think you understood the content of the article? (scale 1-5)
2. Was it helpful to have everything (all the components) always available? /How do you feel about having everything around you?
3. What do you think about using your body to such an extent to navigate?
    a. How did it affect the reading experience?
    b. Did you feel that you understood more or less by using gesticulations to navigate and interact?