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Enhancing Remote Assistance Tasks using Mixed Reality: Examining User Behavior and Experience

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Résumé

L'expansion des entreprises et la mondialisation ont rendu la collaboration à distance de plus en plus courante. Par conséquent, la collaboration à distance a augmenté en réponse aux contraintes géographiques. Parmi les différents types de collaboration à distance, l'assistance à distance est devenue un outil essentiel dans divers secteurs, notamment la fabrication, la santé et le soutien technique, permettant aux experts externes de guider les techniciens sur site en temps réel malgré les séparations géographiques. L'assistance à distance est devenue partie intégrante des entreprises et des technologies plus avancées ont été développées. La technologie de réalité mixte est une technologie émergente qui peut être utilisée dans l'assistance à distance. La littérature examinée démontre les avantages de la réalité mixte en permettant aux participants d'accomplir leurs tâches efficacement et d'améliorer les communications efficaces. Cependant, peu d'études se sont intéressées à la manière dont cette technologie influence le comportement de communication des experts et des techniciens.

Le comportement de communication est un facteur crucial dans l'expérience utilisateur, en particulier dans les scénarios d'assistance à distance où le moyen de communication joue un rôle important. Comprendre comment les technologies de communication, telles que la réalité mixte, façonnent le comportement des utilisateurs experts et techniciens dans les communications d'assistance à distance peut fournir des informations précieuses sur leur expérience utilisateur, optimisant ainsi la technologie. Compte tenu de ces défis et avancées, cette recherche utilise la théorie de l'ancrage communicationnel pour étudier comment la réalité mixte influence le comportement et les perceptions des utilisateurs lors de l'assistance à distance.

Une expérience de laboratoire contrôlée a été menée pour recueillir des données auprès de 64 participants, qui ont joué le rôle d'experts et de techniciens dans 32 séances expérimentales utilisant soit la réalité mixte, soit la vidéoconférence traditionnelle. Les données qualitatives et quantitatives ont ensuite été analysées. Nos analyses ont démontré que les participants présentent des coûts de l'ancrage communicationnel significativement plus bas en réalité mixte. Nos résultats suggèrent également que les différents rôles dans l'assistance à distance perçoivent la technologie de communication différemment, les experts signalant une facilité d'utilisation et un meilleur soutien pour la technologie de réalité mixte que pour la vidéoconférence, tandis que la perception des deux technologies de communication par les techniciens ne montre pas de différence significative. De plus, plusieurs problèmes d'utilisabilité ont été identifiés sur le dispositif de réalité mixte lors de l'analyse post-hoc concernant les aspects d'ajustement et de personnalisation.

Cette recherche a élargi les connaissances existantes en étudiant les modèles de communication influencés par la technologie de la communication. Nous avons aussi découvert des problèmes d'utilisabilité qui peuvent aider à raffiner et à personnaliser les technologies de réalité mixte pour améliorer l'expérience utilisateur des experts et des techniciens. Cette étude fournit également un aperçu de la manière d'adapter la formation des utilisateurs pour une meilleure adoption de la technologie de réalité mixte dans l'assistance à distance.

Mots clés: Assistance à distance, Collaboration à distance, Réalité mixte, Réalité augmentée, Visioconférence, Expérience utilisateur, Comportement de l'utilisateur, Utilisabilité, Ancrage de la communication, Charge cognitive

Méthodes de recherche: Expérience en laboratoire, Observation directe, Analyse quantitative, Questionnaire

Abstract

Business expansion and globalization have made collaboration across distances increasingly common. Consequently, remote collaboration has increased in response to geographical constraints. Among various kinds of remote collaboration, remote assistance has emerged as an essential tool in various industries, including manufacturing, healthcare, and technical support, allowing offsite experts to guide onsite technicians in real-time despite geographical separations. As remote assistance has become an integral part of businesses, more advanced technologies have been developed. Mixed reality technology is one emerging technology that can be used in remote assistance. Existing literature demonstrates the benefits of mixed reality in enabling participants to complete their tasks efficiently and enhance effective communications. However, few studies have focused on how this technology influences the communication behavior of experts and technicians.

Communication behavior is a crucial factor in user experience, particularly in remote assistance scenarios where the medium of communication plays a significant role. Understanding how communication technologies, such as mixed reality, shape the user behavior of experts and technicians in remote assistance communications can provide valuable insights into their user experience, thereby optimizing the technology. Given these challenges and advancements, this research uses the theory of communication grounding to investigate how mixed reality influences user behavior and perceptions during remote assistance.

A controlled laboratory experiment was conducted to collect data from 64 participants, who participated in the role of experts and technicians in 32 experimental sessions using either mixed reality or traditional videoconferencing. Qualitative and quantitative data were subsequently analyzed. Our measurements demonstrated that participants exhibit significantly fewer communication grounding costs on mixed reality. Our finding also suggested that different roles in remote assistance perceive communication technology differently, with the experts reporting significantly better usability and supportiveness for mixed reality technology than videoconferencing, while the technicians' perception of the two communication technologies does not show a significant difference. Furthermore, several usability issues were identified on the mixed reality device during post-hoc analysis concerning fitting and personalization aspects.

This research expanded existing knowledge by investigating communication patterns influenced by communication technology. We also discovered usability issues that can help to refine and personalize mixed reality technologies to improve the user experience of experts and technicians. This study also provides insight into how to tailor user training for better adoption of mixed reality technology in remote assistance.

Keywords: Remote assistance, Remote collaboration, Mixed reality, Augmented reality, Videoconferencing, User experience, User behavior, Usability, Communication grounding, Cognitive load

Research methods: Laboratory Experiment, Direct Observation, Quantitative analysis, Questionnaire

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I am also deeply thankful to my lead researcher and friend, Edward Opoku-Mensah, who worked on designing and pretesting the experiments for this study before I joined, ensuring that the data collection was robust and reliable. Our successful collaboration has not only enriched my understanding of the research process but also led to a wonderful data collection experience. Edward's continued support and encouragement throughout the study made my thesis journey more manageable and enjoyable.

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Chapter 1: Introduction

With globalization and expanding of business organizations, physical distance creates challenges in collaborative work (Olson & Olson, 2000). Effective communication and teamwork are essential and are increasingly dependent in various industries with increasingly geographically separated teams. To address these challenges, organizations allowed their employees to work remotely. The proportion of working remotely has increased gradually over time (Attaran et al., 2019). This shift towards remote work has not only dynamically transformed the traditional workspace but also has opened up a new horizon for people and companies to explore the benefits of remote work. Thanks to remote work and collaboration, which refers to the capability of working and collaborating from any location at any time, enable them to better tailor their schedules to fit personal or family needs for better work-life balance, thus benefiting employees with greater independence and flexibility, potentially boosting their job satisfaction and therefore productivity (Chatterjee et al., 2022; Popovici & Popovici, 2020). This attracted more and more organizations to re-evaluate their policies and practices to accommodate these new ways of working, recognizing that encouraging a supportive remote work environment can lead to the attraction of wider talent source, easier employee retention and even promoting innovation as they no longer have to spend their efforts and time traveling. As organizations adapt to this new mode of operating an office, in order to further enhance overall efficiencies and engagement, innovative tools and technologies are also being developed to facilitate seamless communication and collaboration among remote teams.

With a growing number of businesses adopting these advancements, the demand for innovative digital solutions for remote collaboration continues to grow, and the mobility restrictions imposed during the recent COVID-19 pandemic have further accelerated this shift (Gifford, 2022; Waizenegger et al., 2020). More companies are adopting remote work all over the world intending to prioritize employee's health and well-being, while trying to maintain the businesses' productivity (Gifford, 2022; Greenstein, 2021; Waizenegger et al., 2020). The dramatic increase in remote work has highlighted the significance of remote collaboration tools and accelerated their adoption in professional settings. As a result, we now have more tools and experience to conduct more of our work remotely (Meis et al., 2024). This transformation has not only changed the way teams communicate but also created room for flexibility that allows organizations to adapt themselves dynamically to the changing market environments. The flexibilities have provided the companies the ability to reduce operational costs while increasing efficiency. For example, organizations have leveraged these technology tools to foster more remote collaborations by having a professional in one place, instructing an on-site worker who is not a specialist to accomplish specific tasks. This way businesses can not only save costs from having expensive personnel stationed in every workstation but also lower the downtime by enabling technicians to receive instant visual instructions from experts and therefore improving problem-solving speed (Canelón et al., 2024; Naumov et al., 2021).

One type of remote work which has experienced a remarkable increase since COVID is remote assistance (Fuller & Tohani, 2020). Remote assistance refers to supports in which a remote user, the expert, typically instructs or guides a local non-expert user, the technician, through accomplishing some specific tasks (Fidalgo et al., 2023). This process is a specific instance of remote collaboration. In this research, we will study remote assistance working on physical tasks, where on one end a technician is being guided through the tasks by an expert on the other end via certain communication technologies (Fakourfar et al., 2016; Wolfartsberger et al., 2020) to work on physical three-dimensional objects in the real world (Alem et al., 2011; Fussell et al., 2004; Kraut et al., 1996; Lanir et al., 2013). Examples of this would include the technician and expert working together to fix a piece of machinery at the technician's location. During this process, an on-site technician holds a device to capture the object while seeking help, and the expert analyzes the live video and provides assistance in real-time by giving verbal instructions. Technicians have to follow the guides and cues to complete the task. Experts need to focus on the video while technicians need to focus on the physical object in order to minimize error and enhance productivity.

Remote assistance can occur using a variety of communication technologies and traditionally included audio calls or videoconferencing. Videoconferencing is a communication technology that has revolutionized collaboration in different industries, enabling teams to talk and see each other seamlessly (Bly et al., 1993). Therefore, it is widely used as a tool for remote assistance

(Blattgerste et al., 2017; Fussell et al., 2004). The benefits of video remote assistance include accessibility without geographical limitations or timing barriers. With today's high population of smartphone users (Statista, 2025), videoconferencing is almost immediately available and is also a low-cost technology. This accessibility allows technicians to receive real-time support from experts in time, ensuring that the issue can be addressed promptly and efficiently, therefore lowering the waiting time. However, there are also limitations arose by this technology. One of the constraints involves user difficulties in explaining details, such as a technician might face difficulties verbalizing the texture of a substance when it is in the medical field, or an expert faces difficulties describing a complex procedure or pointing out a direction on an instrument over videoconferencing. Another constraint is the scenario where technicians have difficulties holding the device, for example, when they need both hands to work on a task, or they are at a high-risk location such as atop an electrical transmission tower, where it is difficult to manage the communication technology for videoconferencing. These challenges can hinder the ability to perform tasks effectively while communicating simultaneously with the expert, thus leading to higher mental burden (Da Silva et al., 2011; Zhou, 2023), less effective task completion (Iksan & Mardhia, 2023), longer assistance sessions, and lower user satisfaction compared to in-person assistance. This highlights the need for more intuitive solutions or hands-free devices that would allow the technician to focus on their work without compromising the quality of the support that they receive. Such communication technology could include augmented reality (AR) devices (Blattgerste et al., 2017; Oyama et al., 2021), mixed reality (MR) devices (Fidalgo et al., 2023; Fuller & Tohani, 2020; Oyama et al., 2021; Rebol et al., 2021), or smart helmets (Fuller & Tohani, 2020) equipped with voice recognition and real-time data feeds, enabling technicians to receive guidance while keeping their hands free for critical tasks.

More and more remote assistance sessions currently involve the use of mixed reality technology (Fuller & Tohani, 2020; Rebol et al., 2021). Augmented reality is a mixture of real and virtual environments, accomplished by technologies that add an overlay of virtual content onto the real vision, while mixed reality refers to technologies that offer functionalities to manipulate the virtual objects on top of the portion of augmented reality (Milgram & Kishino, 1994). Augmented reality remote assistance offers a means to support newcomers on-site by guiding personnel through the maintenance process with novel visualizations (Obermair et al., 2020). But with MR technology, maintenance technicians can display the machine to be repaired in 3D vision and then move or rotate it as desired so that they learn better about it and perform their task more quickly, or show the mechanic labels on the vision for individual parts of the device and the work instructions (Mehler-Bicher et al., 2023). MR technology also offers a hands-free solution through special eyeglasses or headsets, reducing cognitive load because technicians no longer need to manage the filming of the instruments they are working on. Therefore, MR technology provides a more immersive experience with better communication and task completion (Bun, et al., 2021), as it not only helps technicians to have a better understanding of the procedural steps but also reduces the chance of errors leading to increased efficiency and productivity in maintenance operations. However, MR technology comes with drawbacks, including a deeper learning curve, as users need to learn how to use the device, or potential user discomfort because of the device size and weight which affects user experience.

1.1 Research Objectives and Questions

This research aims to explore the impact of MR technology on user communication in remote assistance. The importance of this study is underlined by the increasing demand and relevance of remote assistance across various industries, because of the recent global challenges such as different pandemics, wars, geographic separations, and rising travel costs which have significantly sped up the shift toward remote work across various industries and therefore remote assistance has become increasingly vital (Fidalgo et al., 2023). MR technology is becoming a promising tool for facilitating remote assistance. MR technology enables experts to guide on-site personnel more effectively by overlaying digital information on the physical environment without being physically present (Oyama et al., 2021). This approach reduces the need to deploy skilled experts to every physical work site, creating considerable cost savings, which is very important for the companies to maximize profit. Furthermore, the market for MR technology devices is projected to grow rapidly over the next decade (Nguyen et al., 2024), indicating its increasing significance in future industries. Other than commercial businesses, MR tools are also being used with increasing frequency in the medical field and areas of education. Considering this rapid growth in MR technology and the increasing reliance on remote assistance, it is important to understand not just the efficiency of MR technology but also how users experience and perceive its application during remote assistance tasks.

User experience is a critical factor that influences customer trust, satisfaction, and loyalty. Key aspects such as ease of use, reliability, effectiveness, and efficiency shape how users evaluate a technology (Schrepp et al., 2017a). Multiple studies identified various factors that MR technology is improving productivity and user feedback in remote assistance (Fidalgo et al., 2023; Oyama et al., 2021; Rebol et al., 2021). Although remote assistance is recognized as a key strategy for enabling effective knowledge transfer within organizations, introducing MR technology to replace traditional videoconferencing presents new challenges and opportunities. The adoption of MR technology introduces a learning curve and new adaption for experts and technicians, which can be intimidating for those who are unfamiliar with wearable devices or spatial view visions. While previous studies suggest MR technology can reduce cognitive load, enhance task effectiveness, and improve communication efficiency, user experience is also heavily influenced by the communication process itself, particularly in remote assistance scenarios. Therefore, the critical research problem lies in evaluating whether the benefits of MR technology in enhancing communication between experts and technicians while reducing cognitive load would truly outweigh the potential challenges associated with the learning curve and user adaptation.

Previous studies on remote assistance have compared the difference in various aspects of user experience between MR technology and videoconferencing (Fidalgo et al., 2023; Oyama et al., 2021; Rebol et al., 2021), and subjective feedback often suggests that MR technology provides a superior experience. However, the communication behavior of the two user types, experts and technicians, and their communication experience of using MR technology in remote assistance remains relatively unexplored. There is a lack of research assessing whether objective communication behaviors of experts and technicians during remote assistance reflect the same positive impact on the general user experience in practical, real-world remote assistance settings. Therefore, the noticeable gap between how MR technology affects user experience and how it affects remote assistance, is the user behavior of experts and technicians that the MR technology influenced. Understanding how communication behavior challenges and technology-specific factors impact the experience of both user types is crucial for bridging the gap between user perception and measurable performance outcomes when using MR technology. This would require an investigation not only from a subjective perspective but also through observable, objective communication behaviors during remote assistance tasks. Addressing this gap is essential because, with the current understanding of subjective satisfaction, we would also need objective communication patterns from the two roles that can help us to determine whether MR technology genuinely enhances remote assistance or merely creates an illusion of improved efficiency and usability due to faster task completion. Thus, this research aims to bridge the gap between the subjective experience and what happens between experts and technicians during communication in different communication technologies: MR technology and videoconferencing. Hence, this thesis attempts to answer two research questions:

1. How does mixed reality technology influence communication behavior between remote experts and on-site technicians during remote assistance tasks compared to videoconferencing?
2. How do perceptions of experts and technicians vary between mixed reality technology and videoconferencing in remote assistance tasks?

This study is necessary to provide deeper insights into the user experience of MR technology based remote assistance, not only from a subjective user standpoint but also through more objective observations of user behavior. To examine these research questions, we draw on the theories of communication grounding and cognitive load. Communication behaviors have been explained by the theory of communication grounding (Clark & Brennan, 1991), which shows us how to look for evidence of attempting to communicate. This process of building mutual understanding between experts and technicians during remote collaboration plays a crucial role in successful remote work, especially when complex tasks and instructions are involved (Olson & Olson, 2000). On the other hand, cognitive load is known as the mental processing power required to use a product (Sweller, 1988). Therefore, through the lens of the theory of communication grounding and cognitive load, this research could explore how MR technology impacts grounding behaviors in remote assistance sessions, compared to videoconferencing.

1.2 Contributions

The insights gained from this research will contribute significantly to both the academic understanding and practical application of communication technologies in remote assistance environments. From a theoretical perspective, this study will utilize current knowledge of communication grounding to explain how experts and technicians interact with communication technologies and how these interactions influence their experience. The findings are expected to reveal differences in behaviors from experts and technicians and their preferences when utilizing MR technology compared to videoconferencing, shedding light on the refinement of communication technologies for better user experience among remote assistance environments. By analyzing these differences, the research aims to propose targeted enhancements that can optimize remote communications, ultimately leading to more supportive and user-friendly remote collaboration solutions.

In summary, this study seeks to bridge the gap between the theoretical understanding and real-world application of MR technology in remote assistance, offering valuable guidance to both researchers and industries for optimizing related communication technologies.

Table 1 outlines my contributions and responsibilities in the research.

Table 1. Student Contribution and Responsibilities in the Research.

Research Process	Student Contribution
Research Question	Defining the research questions - 60% - My supervisor started working on this topic with one PhD Student (Edward Opoku-Mensah). She taught me how to discover what was interesting, where the research gap lies, how to define a research question, and what theory might be helpful for what I am interested in investigating.

Literature Review	Searched the databases for academic articles - 100% Writing of literature review - 100% - I received advice from my supervisor on how to structure and modify the review
Research Model and Data Collection Methodology	Define the research model - 85% - I defined the 4 behaviors to be examined in the experiment recordings. I received advice from my supervisor on how to structure and modify the model. User perceptions questionnaires - 95% - Searching for validated questionnaires for appropriate research variables. Questions were added to the PhD Student's Qualtrics questionnaire, which already contained demographic questions.
Recruitment	Participants recruiting (after pre-tests) - 35% - The participants were recruited through the institution's panel by an automatic mechanism. In addition, I advertised the recruitment on several social media and school communities and contacted participants for the screening registration. - I worked together with one PhD Student (Edward Opoku-Mensah) to recruit participants. Edward managed the time slots and contacted the registered participants.
Laboratory Experiment	Conducting the experiment - 25% - I worked together with one PhD Student (Edward Opoku-Mensah) to conduct the experiments. He worked with my supervisor to design the experiment and all data collection instruments. I joined at the data collection stage after the pre-tests. During data collection, we were both present for all experiment sessions. He took the lead in communicating directly with participants and I reset the instruments between

	tasks and after the experiments. We took turns to prepare the instruments, documents, and questionnaires before and after the experiments.
Data Analysis	Qualitative Data Analysis - 100% - I reviewed all recordings of the experiments several times to code the 4 behaviors and observe extra behaviors for qualitative findings. Quantitative Data exporting, cleaning, formatting, and combining - 95% - I received help from one PhD Student (Edward Opoku-Mensah) for questionnaire data export. Statistical Analysis - 100% - Analysis was performed using the SAS online platform. I researched the valid statistical test for the data and hypothesis analysis. Results interpretation - 90% - I received help from one PhD Student (Edward Opoku-Mensah) for excluding invalid data. I also received help from my supervisor with analyzing the data and interpreting the results.
Thesis Writing	Contribution in writing the thesis - 100% - Throughout the process, my supervisor guided me with detailed feedback. Her help improved the context and writing of this thesis. Grammatical and phrasing suggestions were provided by language editors for within-sentence improvements. The French translation of the Abstract was produced using Google Translate.

1.3 Thesis Structure

This thesis follows the classic format. Chapter 1 is the introduction explaining the phenomenon, research objectives, and contributions. Chapter 2 is the literature review of existing literature covering the topics of remote assistance and different tools being used. Chapter 3 detailed the formation of the research model and hypotheses development based on relevant theory. Chapter 4 introduced the experiment and methodology of collecting data. Chapter 5 presents the analysis results of the data. Chapter 6 discusses the results and implications. Finally, Chapter 7 concludes the contribution of the thesis and future possible studies.

Chapter 2: Literature Review

This chapter focuses on topics related to remote assistance settings, their usages, and developments, as well as MR technology and its impact on communication. A comprehensive review of existing literature was done, drawing from relevant research on different communication technology tools and their usage in remote assistance to identify the research gaps this study aims to address. The findings will then help establish the foundation for the research model and hypothesis development in Chapter 3.

2.1 Literature Review Objective and Methodology

In this study, the first objective of the literature review is to understand remote assistance. This involves examining the traditional tools and technology that facilitate remote assistance as well as analyzing the effectiveness of these tools in enhancing user experience across different industries. By exploring this area, the research can provide insight into how remote assistant tools can be optimized for better user experience. The second objective is to understand the MR technology communication tools. This includes comparing with more traditional videoconferencing, and evaluation of the usage of the MR technology in helping users minimize the difference between face-to-face interaction and remote interactions, to explore the potential to improve the experience using these technologies.

The literature search was mainly done using 4 databases: Google Scholar, ACM, IEEE Xplore, and JSTOR. For each objective laid out above, I used different keywords and criteria to search for literature to ensure a comprehensive understanding of the existing research and identify the gaps that my study can address. Remote assistance keywords included *remote assistance, remote support, remote maintenance, remote troubleshooting, distance support, remote collaboration,* and *teleassistance*. In MR technology, I used *mixed reality, MR, augmented reality, AR, virtual reality, VR,* and *immersive technology*.

To ensure comprehensive research coverage, different combinations of keywords were explored. In the initial stages of the search process, it was observed that using all relevant keywords simultaneously in a single query often resulted in very limited or no search results. To overcome this limitation and to narrow down the search to a specific area of study, a strategic approach to select and combine keywords was adopted. Keywords were organized into two main groups: 1) Mixed reality technology related terms, and 2) remote assistance related terms. The search strategy involved pairing selected keywords from the MR technology group with those from the remote assistance group. A broad search was first conducted, which was then progressively narrowed through the application of additional constraints. Sometimes, replacing keywords with related terms, for instance, using virtual support instead of remote support, or distance rather than remote, can help to locate studies that are more closely aligned with the research focus. Narrowing and filtering down the search results can also help to eliminate irrelevant papers. An initial search using a broad set of keywords yielded over 6,000 results. To refine the search and improve its relevance, exclusion criteria were applied by specifying keywords that should not appear in the results. This step effectively reduced the number of studies to approximately 1,200. Subsequently, further adding or replacing keywords with more targeted ones produced a smaller set of around 100 studies, which had a higher relevancy.

The search results show that the method applied for the literature review is feasible. While all the findings were considered, studies or research of technologies that are obsolete or too old, such as the comparison between telephone assistance and video call assistance, were excluded because the use case was not applicable. Screening and applying exclusion keywords, such as assistive technology, remote control, and immersive control, was particularly effective in filtering out irrelevant studies because there are plenty of studies on the other topics that come with the keywords used.

The structure of the literature review follows the objectives of the literature review. This includes the review outcomes of remote assistance, MR technology, and the comparison of communication technologies utilized in remote assistance.

2.2 Remote Assistance

Remote assistance refers to a technology driven method of providing real-time support and guidance to users or workers at a different location (Fakourfar et al., 2016). The remote user, usually called the *expert*, provides assistance to the local novice user, whom we call the *technician*, to complete a task working on a physical object (Alem et al., 2011; Kraut et al., 1996; Lanir et al., 2013). This collaboration occurs through various communication technologies, enabling effective guidance without the need for physical presence. Remote assistance technology can significantly change the business operations and collaboration between workers (Attaran et al., 2019; Chatterjee et al., 2022; Marion & Fixson, 2021; Olson & Olson, 2000; Popovici & Popovici, 2020).

Remote assistance is growing in certain industries (Attaran et al., 2019; Rebol et al., 2021). When there is a geographical distance between various work sites and offices, using such technology can help save costs as each site does not have to have their own highly trained experts, or can reduce the traveling time and costs of experts between sites. Different fields of business have adapted this technology, such as healthcare, aviation, manufacturing, and engineering, in which efficient support can enhance productivity and reduce operational costs. Field technicians receive real-time instructions from experts to troubleshoot complex machinery (Obermair et al., 2020). Surgeons and healthcare professionals remotely assist workers and patients (Worlikar et al., 2023). Remote learning and interactive hands-on training are delivered through remote assistance technologies (Dunleavy et al., 2009).

Real-time video with audio conferences over the Internet (videoconferencing) are very common in facilitating communications across offices (Bly et al., 1993). It is a two-way simultaneous communication tool, which allows for seamless business activities and the exchange of ideas, regardless of graphical barriers. Remote assistance in companies is enhanced by adopting this technology (Blattgerste et al., 2017; Domova et al., 2014; Fussell et al., 2004; Karis et al., 2016). Daft and Lengel explained that, during communication, different media and technology offer various extents of information exchange (Daft & Lengel, 1986; Krauss & Weinheimer, 1966), which can significantly impact user engagement and experience. The ability to allow information to be exchanged for understanding in a communication within a time interval is defined as the richness of information. The more efficiently a communication medium can bridge differing perspectives and resolve ambiguity through information exchange, the richer the medium. With both audio and video channels transmitting between both sides of users to provide situational awareness, videoconferencing is regarded as a rich medium of communication (Daft & Lengel, 1986; Schmidt, 2002).

Although videoconferencing is a rich medium, research shows that remote support via videoconferencing has a higher cognitive load than face-to-face (Da Silva et al., 2011; Schmidt, 2002). In user experience design, cognitive load is known as the mental processing power required to use a product (Paas & Van Merriënboer, 1993; Skulmowski & Rey, 2017; Sweller, 1988). Each user has their own ability to process information. If there is too much information needed to be processed at once, the user's overall performance will be degraded (Iksan & Mardhia, 2023). The challenge encountered by people communicating via videoconferencing is that technicians often struggle to operate the equipment while simultaneously taking the video (Niedermayr et al., 2022). It is a sign of cognitive overload. Because of this, disruptions in communication would also occur because when technicians manually adjust cameras, they sometimes position the camera wrongly (Mohr et al., 2020). It is a sign of cognitive overload. Videoconferencing can also lead to less perceptible spacing and gestures (Luff et al., 2003), which means that in order to compensate for the missing visual cues, one end of the users would need to spend extra effort to convey the information, while the other end would need extra processing effort to understand the context. This is the same when a user makes some gestures that cannot be conveyed through the videoconferencing tool, therefore the user on the opposite side of communication does not know what is being referred to (Heath & Luff, 1991). In summary, the literature found that because the goal of remote assistance technology is to enable remote users to establish a shared understanding, more advanced communication technologies are being developed to improve the communication between experts and technicians.

2.3 Mixed Reality Technology

Mixed reality technology combines digital and physical visions, showing users virtual content overlaid on real vision (Milgram & Colquhoun, 1999; Milgram & Kishino, 1994; Mohr et al., 2020). MR technology enables users to interact with digital content while still being aware of their physical surroundings simultaneously. Milgram and Kishino (1994) introduced the Reality-Virtuality Continuum, noting that there are a few categories of technology in extended reality, ranging from fully real environments to fully virtual ones. This continuum helps in understanding how different technologies can enhance the user experience through different degrees of immersion and interaction with the digital elements embedded in the technology. Augmented Reality (AR) technology provides an overlay of virtual objects onto the real world but does not offer interaction. Examples of this technology include AR navigation apps and AR video playing. Virtual Reality (VR) technology provides fully virtual visual content that immerses users in a completely different environment, cutting off the real world. Examples of this technology are VR tourism applications and VR gaming software. Mixed Reality (MR) technology offers users visual content manipulation functions, on top of the functionalities that are also offered by AR, which provide real physical vision as well, allowing for the dynamic interaction mentioned above. Examples of MR technology include training simulation applications and collaborative design software.

MR technology integrates several components to create interactive environments. Head-mounted displays provide users with an immersive experience, which can integrate real-time rendered virtual elements into physical view and display to the user instantaneously (Fidalgo et al., 2023). Devices such as Microsoft HoloLens provide functionalities to users to interact with virtual elements. MR technology devices utilize sensors to facilitate spatial mapping, a crucial process for the seamless and immediate merging of virtual and physical realms (Fidalgo et al., 2023; Lin et al., 2024). This is achieved through continuous real-world environment capture, ensuring precise alignment of digital objects with their physical counterparts. It also scans the view to detect gestures for immediate processing. MR technology adopts gesture and voice recognition (Fidalgo et al., 2023; Niedermayr et al., 2022). Users can interact with virtual elements using hand gestures and voice commands, which is accomplished by advanced software programs that can track users' actions and speech, and process in real-time, therefore improving user engagement and experience. By integrating network computing, MR applications can stream real-time video and sounds, thus facilitating collaboration between remote users. By adopting these functionalities, MR technologies create an interactive environment to simulate that digital objects can be manipulated like physical ones (Schmalstieg & Höllerer, 2016).

This innovative technology enhances collaboration by providing immersive experiences that facilitate real-time interaction and information sharing, ultimately bridging the gap between virtual and physical spaces. MR technology therefore is used by organizations for an expert to guide a non-expert through remote assistance (Oyama et al., 2021). MR technology enables real-time guidance and holographic annotations, allowing users to visualize complex instructions more intuitively, therefore significantly enhancing remote assistance (Mohr et al., 2020). Using augmented reality technology (Blattgerste et al., 2017), which is also adopted in MR technology (Lin et al., 2024), in remote assistance sessions can significantly reduce time and error in task completion. It also improves safety while following the instructions. Furthermore, studies indicate that the application of MR technology improved the efficiency of conversations and thereby facilitated quicker task completion (Bun, et al., 2021). Using such technology also led users to be more focused on the task and provide higher work quality (Richardson et al., 2014). More specifically, research shows that visual annotation cues, such as drawing annotation, help users perform collaborative tasks easier and with better understanding, therefore both technicians and experts are making fewer errors and can complete the tasks faster (Lin et al., 2024; Obermair et al., 2020; Teo et al., 2018). It is also shown that the performance of the pen-based drawing tool with auto-erase features enabled on remote assistance is comparable to side-by-side assistance (Fussell et al., 2004). Conversation over remote assistance is also more efficient with pen annotation compared to audio and video conferences. Multiple-user collaboration is possible using MR technology, allowing the users to interact with the same digital content together, making it an effective tool for remote assistance.

A few studies compared AR and MR technology with videoconferencing in terms of cognitive load, efficiency, and communication quality for remote assistance. Research demonstrated that remote assistance done via MR technology has a lower cognitive load than videoconferencing (Pietschmann et al., 2025; Seeliger et al., 2023; Tang et al., 2022). The usability of such technology is reported higher as well. Reducing the cognitive load of personnel effectively enhances work efficiency and improves the overall user experience (Zhou, 2023). Some recent research also emphasizes the importance of keeping a low cognitive load as a strategic reason when creating MR interfaces (Narayanamma et al., 2024; Xia & Wu, 2021).

These findings demonstrate that MR technology can improve the efficiency of communication and promote a more intuitive and immersive experience for remote collaboration. MR applications are now moving beyond experimental use toward achieving commercial success and are becoming increasingly interesting for companies (H. Zhang et al., 2020; J. Zhang et al., 2022; Mehler-Bicher et al., 2023; Nguyen et al., 2024). As organizations increasingly adopt mixed reality solutions, they are discovering new ways to enhance remote assistance across various industries.

Chapter 3: Research Model and Hypothesis

The research model depicts the impact of Mixed Reality (MR) technology on user experiences during remote assistance tasks. Taking a holistic user experience approach, we want to study not only user perceptions but also actual user behavior. The model focuses on the comparison between the use of MR technology and videoconferencing, aimed at answering two primary research questions:

1. How does mixed reality technology influence communication behavior between remote experts and on-site technicians during remote assistance tasks compared to videoconferencing?
2. How do perceptions of experts and technicians vary between mixed reality technology and videoconferencing in remote assistance tasks?

3.1 Research Model

The research model is formed based on prior literature in the domain of communication technology, user behavior, and user experience studies. In addressing Research Question 1, four hypotheses are proposed, grounded in the principles of the theory of communication grounding. For Research Question 2, Cognitive Load Theory serves as the basis for formulating two hypotheses. Our resulting research model (see **Figure 1**) comprises one independent variable, which is communication technology (MR technology vs. videoconferencing), and two groups of dependent variables, which are user behavior and user perceptions. User behavior and user perception will be further expanded to specific variables to be investigated and the relationships between these variables are to be examined through hypotheses, which are described in the hypothesis formation section.

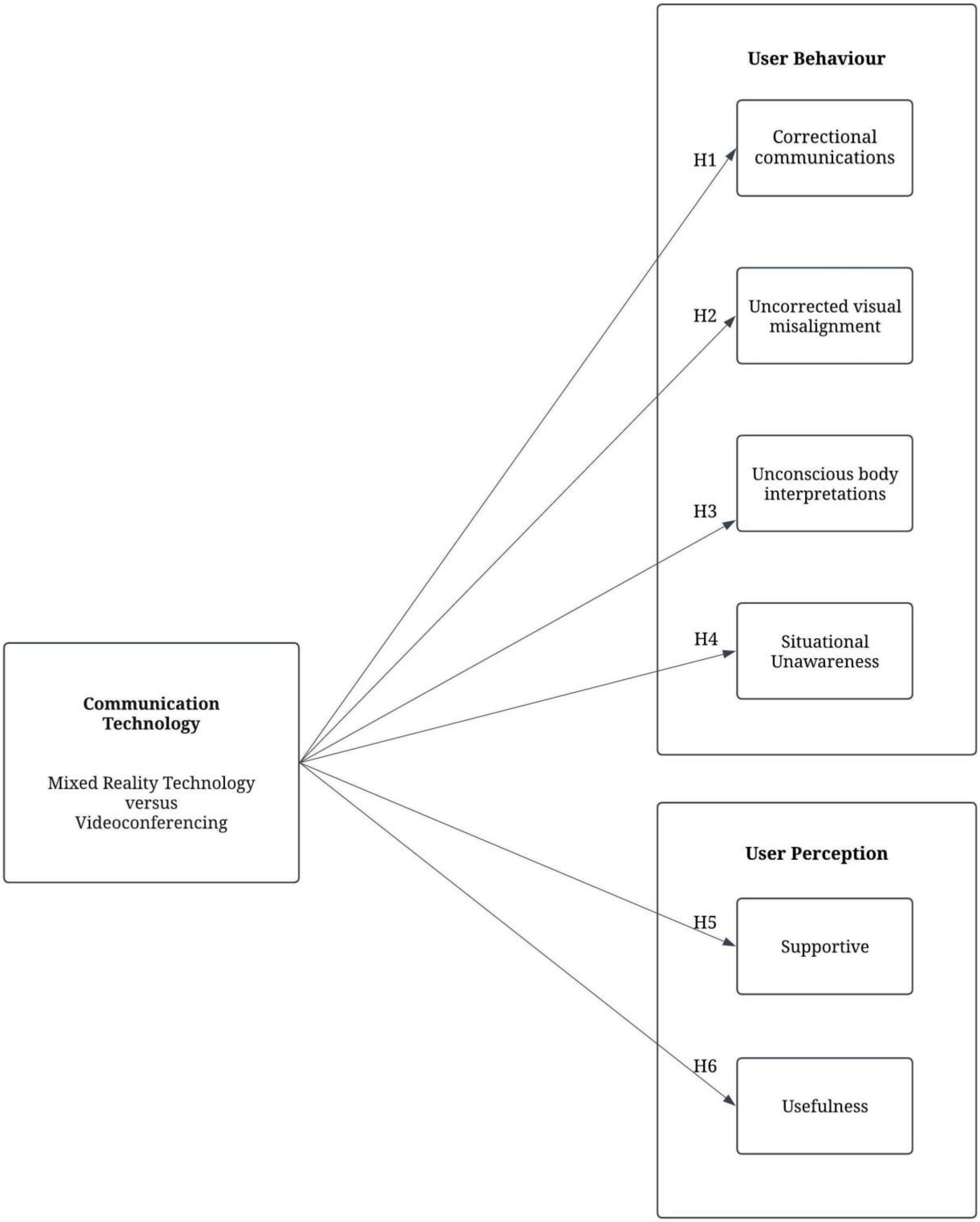


Figure 1. Research Model

3.2 Theories of Communication Grounding and Cognitive Load

As illustrated earlier, this study draws on two established theories for hypothesis development: the theory of communication grounding and the cognitive load theory. This section presents the theoretical basis supporting the development of the research model and hypotheses.

The theory of communication grounding (Clark & Brennan, 1991) can be applied to bridge the gap in our understanding of how the usage of MR technology tools and videoconferencing influences user behavior through the establishment of common ground in the context of remote assistance. Grounding in communication, where information is presented by a speaker to an addressee, is conceptually divided into a presentation phase, involving the "evidence" which a speaker presents information through conversations in the form of utterances, and an acceptance phase, where the addressee indicates understanding through utterances, by giving evidence to show understanding or acknowledgment of the presented information (Brennan, 1998; Clark & Brennan, 1991; Clark & Schaefer, 1989). This process ensures mutual understanding and integrates both speech and gesture in dialogue (Bavelas et al., 2011).

Formulation of grounding involves costs in terms of time, effort, and cognitive load (Clark & Brennan, 1991). Formulation costs are the time and effort to prepare or revise utterances. In remote assistance, that would be the effort to describe the state of an instrument or an instruction. Production costs are the effort involved in producing a message on different mediums of communication. For example, holding a phone to talk involves a higher cost than a head-mounted device. Reception costs are the effort to accept a communication, such as listening versus looking. The addressee looking at the annotations made by a speaker would be easier than listening to a long sentence for the same instruction. Understanding costs are the effort to understand the context of the conversation. The addressee watching the progress of the speaker is easier than listening to a speaker's verbal description when the speaker has to use both hands to do the work. Display costs are the effort to communicate non-verbal context. Nodding, pointing or gestures are often easier than speaking out loud. Fault costs are the cost associated with mistakes made in communication. Examples include the speaker giving an unclear instruction which leads to a misunderstanding, or the speaker holding the phone in the wrong position and capturing an incorrect item. Repair costs are the cost of correcting the message and resending the correct one. Examples include a correctional demand made by the addressee to request the correct information, or the speaker repeating the information, which costs extra time and effort. A cycle of correction and reconfirming is needed to make sure the messages are communicated correctly. Following the least collaborative effort principle (Clark & Wilkes-Gibbs, 1986) that the theory of communication grounding supports, speakers tend to minimize the amount of verbal information they share in the process of establishing common ground, thereby reducing the grounding costs.

Through examining the evidence of grounding costs, we can explain how communication technology affects the effort of the users to establish common ground for successful communication. By analyzing the amount of grounding effort participants must spend to establish common ground for different technologies, we can hypothesize how MR technology affects user communication behaviors.

In the context of model development for the relationships between communication technology and user perceptions, Cognitive Load Theory (Sweller, 1988) is useful to highlight the mental effort required to process information, operate the communication technology, and engage in communication. Cognitive Load Theory explains a framework for understanding how individuals learn and understand information and make use of that information during tasks (Sweller, 1988). It is posited that human cognitive capacity is limited, and learning or task performance is optimized when cognitive load is managed effectively by instructional design. According to the theory, cognitive load is categorized into three distinct types (Chandler & Sweller, 1991). Intrinsic load, which is related to the complexity of the task or information itself. Extraneous load, which refers to the extra cognitive effort required because of poor instructional design or instructions. Germane load, which is related to concept building and knowledge retention in learning progress.

Multiple methods were developed to measure cognitive load (Paas & Van Merriënboer, 1993; Skulmowski & Rey, 2017). These methods include subjective ratings, performance-based measures, and physiological indicators, each providing useful insights into how cognitive load affects learning outcomes and task efficiency and therefore is influencing user experience.

3.3 MR Technology and Communication Grounding

The first four hypotheses use the theory of communication grounding to explore how MR technology influences communication behavior in remote assistance tasks. All the hypotheses associated with the research model are depicted in **Figure 1**. Previous research has shown that MR technology can increase the efficiency of conversations and task completion (Bun, et al., 2021; Lin et al., 2024; Obermair et al., 2020; Teo et al., 2018). We hypothesize that this may be explained by the theory of communication grounding: incorporating MR technology may reduce communication grounding costs by providing a richer and more interactive environment that facilitates user understanding between experts and technicians. However, no research specifically hypothesizes these effects of MR technology. This gap in the literature presents an opportunity for an investigation into how MR technology can influence interactions between communications in remote assistance.

In remote assistance settings, different communication technologies are being adopted to facilitate communication. As observed in the current literature, we learned that, during communication, different media and technology offer various levels of richness of information (Daft & Lengel, 1986; Krauss & Weinheimer, 1966). Richer communication media provides more effective information exchange during communication. Therefore, as MR technology is a highly immersive communication tool, it is expected to provide richer information exchange compared to videoconferencing. In contrast, videoconferencing is not expected to provide as much information as MR technology during communication in a remote assistance session.

With the richer information being exchanged, it facilitates the grounding process in conversations (Clark & Brennan, 1991). Building on the theory of communication grounding, research demonstrated that visual information passed through the communication technology helps the anticipation of knowledge of the other party, and therefore saves the effort for the participant to produce and convey information in the communication (Gergle et al., 2012). For example, during a remote assistance session, if the expert sees the status of the equipment via the communication technology device, the technician may anticipate that the expert would have known the status of the equipment without having to convey this information. The least collaborative effort principle (Clark & Wilkes-Gibbs, 1986) suggests that collaborative effort plays a role in how effectively people can communicate. Using the same example as above, the technician would not describe the equipment status verbally, saving the effort.

The theory of communication grounding has described conversation as collaborative action (Clark & Brennan, 1991). The process by which the conversation participants, who would be the technicians and experts in remote assistance settings, establish a shared understanding of a specific context is called communication grounding. During communication in a remote assistance session, the absence of physical presence hinders the mutual understanding of the context. Extra communication effort is required to bridge the gap, such as the use of descriptive language or explicitly filming pointing and hand gestures, in order to transmit meanings that could typically be easily seen in face-to-face conversations. Clark and Brennan (1991) explained it as a "Formulation cost" of a communication grounding. They provided a framework of grounding in communication to illustrate how people establish shared understanding when they communicate. Experts and technicians have to collaborate actively during the remote assistance session in order to establish common ground, which means they make sure both parties understand the instructions in the same way. Therefore, from the theory, we know that communication grounding takes place in the process by which the experts and technicians attempt to update the common ground (Brennan, 1998; Cho & Rader, 2020; Clark & Brennan, 1991). This process often involves the participants asking questions for clarification, supplying additional explanatory content, or correcting of information. In remote assistance via videoconferencing, both experts and technicians have to spend extra effort to ensure that they are on the same page when discussing the technical details of the physical tool. While for the expert, the "Formulation cost" of the conversation is higher, the "Understanding cost" for the technician is also higher (Brennan & Lockridge, 2006; Clark & Brennan, 1991). In face-to-face communications, a nod or a gesture would be enough to acknowledge the understanding of a message. However, in videoconferencing, the listener may need to say it explicitly. Such actions to confirm understanding are evidence of grounding (Brennan & Lockridge, 2006; Clark & Schaefer, 1989). In case the listener is not able to catch the meaning, either the listener would request clarification, or the speaker would repeat themselves, and in communication grounding, this is regarded as a repair by resubmitting the context (Roque & Traum, 2008). The more time users spend on repairing or resubmitting information, the higher the cost is to achieve a mutual understanding of that communication.

In remote assistance settings, grounding in communication is critical, as experts and technicians must communicate complex instructions effectively and efficiently. Technologies enhancing common ground and grounding processes improve communication efficiency by reducing misunderstandings and minimizing clarification needs (Olson & Olson, 2000). MR technology offers better visual awareness and real-time annotations, therefore it is expected to reduce communication barriers and improve the grounding process. The head-mounted MR technology also frees up a hand, releasing the physical and mental effort for other usages. Drawing on the theory of communication grounding, we hypothesize that MR technology will decrease the frequency of communication errors. This is because MR technology can reduce formulation costs, reception costs, understanding costs, display costs, fault costs, and repair costs in the grounding processes.

Based on the theory and the factors described above, I propose four behaviors that increase the cost of communication grounding, and are potentially reduced by the use of MR technology for remote assistance tasks, depicted in Table 2.

Table 2. List of behaviours being studied

Behaviours	Definition	Source
Correctional communications	Expert requests technician to adjust view.	Modified from Request Repair (Roque & Traum, 2008)
Uncorrected visual misalignment	Camera does not show the area technician is referring to.	Modified from misalignment of the visual field (C. B. Kumar et al., 2015)
Unconscious body interpretations	Expert uses hand gestures that are not visible to technician.	New term

Situational unawareness	Expert pauses due to inability to see equipment status.	Modified from loss of situational awareness (Cooper & Strayer, 2025)

3.3.1 Communication Technology and User Behavior

In remote assistance, it is crucial that the expert can clearly see the physical object that is being discussed. Sometimes the technicians may be too busy or forget to point the camera at the specific area that they are working on. This creates challenges for the expert to fully understand the status of the subject or other nearby factors. Such challenges will lead to frequent interruptions by the expert to clarify or issue corrective instructions to realign the visual field from the technician, which affects grounding (Roque & Traum, 2008). MR technology provides broad visual information to the technician and the visual aspect moves along with the technician's focus as they turn their head. Therefore, MR technology may result in less correctional communication during communication grounding. Thus, we propose:

H1: Teams communicating with MR technology will exhibit lower frequencies of correctional communications on the visual field than with videoconferencing.

During remote assistance via videoconferencing using a phone, technicians must manually control the camera while speaking, which increases cognitive load and often results in misalignment of the visual field (C. B. Kumar et al., 2015). Visual misalignment is a type of fault cost in communication grounding. If it persists, it will lead to an uncorrected visual misalignment, which may further produce a high repair cost in a later stage (Clark & Brennan, 1991). When this happens, it reduces the clarity of the visual information being conveyed. It may lead to pausing of conversation, repeating of utterances, or miscommunication, which may then develop into delayed task execution, frustration, or errors in tasks. MR technology, which provides a broader field of view and will also automatically adjust with head movement, is expected to reduce such occurrences. Thus, we propose:

H2: Teams communicating with MR technology will exhibit uncorrected visual misalignment less frequently than teams communicating with videoconferencing.

During communications, participants often make use of body language, such as hand gestures, to convey information or emphasize points (Masson-Carro et al., 2016). Gestures, along with speech, played a crucial role in establishing common ground during referential communication, showing that gestures and speech are closely coordinated. Therefore, the more gestures the speaker has to make, the higher the cost of grounding. Also, body language, particularly hand gestures, is an important part of communication revealing thoughts in the mind (Arnheim & McNeill, 1994). Unconscious body interpretations are one type of body language and can indicate messages that are difficult to express verbally. During communication grounding, excessive hand gestures reflect difficulty in conveying instructions verbally and the speaker is trying to reduce the display costs in grounding. Since hand gestures reflect a high display cost in the grounding process, fewer gestures made by the expert would indicate that the user experience is better from the expert's point of view. MR technology offers annotation, which is a tool that the expert can use to convey information when it is easier to do so by drawing or writing than by speaking out loud. Research has demonstrated that annotation tools are comparable to hand gestures in face-to-face communications (Fussell et al., 2004; Teo et al., 2018). It is anticipated that using such technology would reduce body interpretations during communication. So, the third hypothesis is:

H3: Teams communicating with MR technology will exhibit unconscious body interpretations less frequently than teams communicating with videoconferencing.

Situational awareness is the perception of elements in the environment within a certain amount of time and space (Endsley, 1995). Loss of situational awareness refers to a reduction in the ability to fully perceive or understand the surrounding environment or context. In videoconferencing, camera positioning issues, multitasking demands, and limited visual context can result in unnoticed contextual changes. Attempts to ground communication may exhibit missed critical details or misinterpretation of the situation. For example, if a tool is adjusted slightly during a session of a videoconferencing, the expert might not notice, leading to extra waiting or missing follow-up instructions. In remote assistance via videoconferencing, the technician has to explain the situation, position the camera, and operate the machine simultaneously. By using MR technology, the technician does not need to position the camera while working on the communication and operating the machine at the same time. This is a form of multitasking, and the level of multitasking is lower with the use of MR technology. As loss of situational awareness, also named contextual blindness in some research, is more likely to occur in multitasking (Cooper & Strayer, 2025), the use of MR technology would be expected to mitigate the issue of situational unawareness. By reducing multitasking, MR technology is expected to enhance the grounding process and deliver more accurate and effective communication than using videoconferencing. Therefore, our fourth hypothesis is:

H4: Teams communicating with MR technology will reduce situational unawareness compared to videoconferencing.

3.4 MR Technology and Cognitive Load

For the next two hypotheses, we draw on the cognitive load theory (Sweller, 1988) to explore how communication technologies can influence user experience. Self-reported user perceptions are employed to compare the effectiveness of MR technology and videoconferencing in reducing cognitive load and enhancing overall experience during remote assistant tasks.

The literature review shows evidence that MR technology has lowered users' cognitive load and enhanced usability (Pietschmann et al., 2025; Seeliger et al., 2023; Tang et al., 2022). The reduced cognitive load and improved usability of MR technology contribute to a more efficient process of establishing common ground between experts and technicians in remote assistance tasks. In videoconferencing, a higher cognitive load can lead to increased repair and resubmission cycles, where participants have to clarify, repeat, or correct misunderstandings.

Research also suggests that different communication technologies offer varying affordances, influencing how efficiently users collaborate and build common ground (Kraut et al., 2003; Schrock, 2015). The way how users interact with a communication technology also impacts their efforts in achieving common ground (Brennan & Lockridge, 2006). Through different affordances, we can explain how the technology affects the effort of the users to establish common ground for successful communication. Understanding this effort is important, as the more information is to be processed at the same time, the higher the cognitive load is for the participants (Sweller, 1988). Cognitive load influences not only the user experience of both parties in the conversation but also affects productivity during the tasks (N. Kumar et al., 2022). By skipping the need to describe the visible information, both parties can enter the next turn of communication for new information on the task at hand.

3.4.1 Communication Technology and User Perception

Time and effort can be measured and utilized in the usability testing of commercial products. It is known as the System Usability Scale (Brooke, 1995). According to System Usability Scale studies, time and effort spent correcting or repeating information are key usability performance indicators (Narayanamma et al., 2024). Delays, misunderstandings, and excessive verbal clarification negatively impact the users' experience of remote assistance as well. Therefore, when MR technology offers spatial mapping, real-time rendering, and annotation technologies, it is expected to give a better user perception of the remote assistance experience. Multiple studies also use the measurement of time and effort as user experience performance indicators (Ahram & Falcão, 2020). The User Experience Questionnaire is also a key instrument for measuring user experiences by collecting users' perceptions and responses (Schrepp et al., 2017a). A shorter version of it (Schrepp et al., 2017b) is also often utilized, allowing for quicker collection of user feedback.

The overall user experience of a person using a product includes their perceptions of supportiveness(Chen et al., 2020; Kuhar & Merčun, 2022), which means how well the technology assists in task completion; And usefulness(Agyeiwaah et al., 2022; Gordillo et al., 2014; Kuhar & Merčun, 2022; Somrak et al., 2021), which means how beneficial the technology is for performance. The technology acceptance model (Davis, 1989) states that user perception of usefulness and ease of use determines the acceptance of a technology. In this study, we evaluate the perceived usefulness and supportiveness of MR technology among both experts and technicians to determine its influences.

From the literature, it is known that the interaction between users' perceptions of utility and the objective qualities of technology influences how individuals communicate and their behavior patterns (Schrock, 2015). We can see that there is a linkage between the perceived supportiveness of technology and the efficiency of communication (Chen et al., 2020), suggesting that improvements in technology can lead to more effective interactions and enhance user communication. A better subjective feedback would demonstrate that MR technology yielded a better user experience.

MR technology provides users with richer information through a broader vision, direct display of annotation, and hands-free interaction (Billinghurst & Kato, 2002). Thus, MR technology provided a lighter communication burden environment through easier vision control and an easier way to convey non-verbal messages via annotation, offering a more immersive and less cognitively demanding communication experience. Freeing one hand also unleashes a lot of effort from operating the camera, especially when the task requires both hands to work together. Because of that, it is perceived that MR technology is more supportive in remote assistance sessions than videoconferencing because of lower cognitive load during usage. Therefore, the fifth hypothesis evaluates whether MR technology enhances users' perception of supportiveness during communication:

H5: MR technology is more supportive than videoconferencing in remote assistance sessions.

Perceived usefulness is a key determination standard of technology acceptance (Davis, 1989; Venkatesh & Davis, 2000). MR technology is expected to provide clearer visual guidance, improve alignment, and reduce miscommunication, making it a more effective tool than videoconferencing. Because of that, it is perceived to be more beneficial for the performance, in other words, a higher usefulness. Therefore, the sixth hypothesis assesses whether MR technology enhances users' perception of usefulness in remote assistance:

H6: MR technology is perceived as more useful than videoconferencing in remote assistance sessions.

Chapter 4: Methodology

This chapter presents the methodology employed for conducting this research. An experimental protocol was designed to investigate the hypotheses and research questions. The protocol includes a controlled experiment, data collection techniques, and analytical methods in order to ensure all variables were carefully controlled and measured throughout the study. By integrating both qualitative behaviors and quantitative data, the study could provide a richer analysis of how these communication technologies impact interactions and experiences among different roles of users in a remote assistance session. The experimental design, participants, instruments, experimental procedures, questionnaire, and measurement techniques utilized in this study are detailed in the following sections to provide a comprehensive understanding of how the research was carried out.

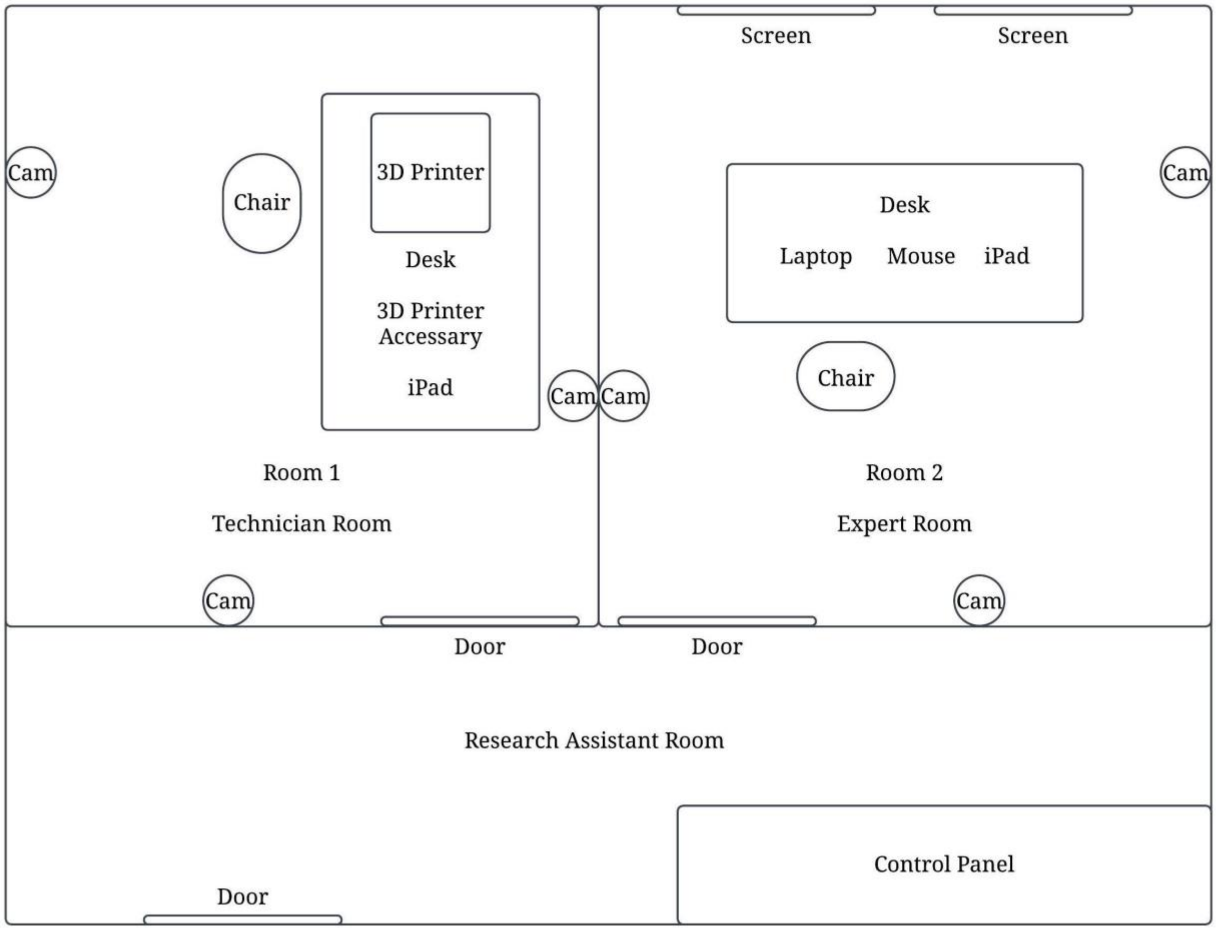
4.1 Experimental Design

To examine the differences in user communications between MR technology and videoconferencing, a controlled experiment was adopted, collecting both the qualitative video data and the quantitative questionnaire data. This allows us to collect both the user's actual behavior data and the user perceptions data from experts and technicians in a remote assistance session, conducted via MR technology and videoconferencing respectively. The video data also allows us to observe various phenomena of communication grounding that happened during the remote assistance sessions, which helps us to identify how different communication behaviors may be influenced by the technology used.

Structured tasks were designed to simulate real-world scenarios requiring effective communication and collaboration for maintenance or troubleshooting procedures in a remote assistance session. In this study, we simulated a remote assistance session involving a technician connecting with an expert in another location regarding some operations on a 3D printer. The technician participated in a task in which he or she needed to set up a 3D printer for other users. In the task, the expert provided remote assistance to the technician on site to finish their job.

To better observe different behaviors in the use of different communication tools, we have designed two tasks: One lower complexity task, which is simpler and with fewer steps in the procedure; and another higher complexity task, which requires a more detailed explanation and with more steps in the procedure. Communication behaviors of both the expert and the technician were recorded and observed to uncover patterns in communication grounding during the remote assistance session. Video and audio of the experiments were analyzed to record the frequency of events, such as corrective instruction, uncorrected visual misalignment, unconscious body interpretations, and loss of situational awareness.

This experiment was conducted under controlled laboratory conditions. The reliability and validity of the findings were ensured through the laboratory's capacity for effectively controlling variables and conditions, thus attributing any observed differences in the results were due to the influence of communication methods rather than other external factors. A randomized counterbalanced design was implemented, with experimental sessions conducted in both the morning and afternoon. This variation in timing and conditions can reduce the influence of the result due to external factors, such as energy level or attentiveness throughout the day. For each experiment session, two participants were recruited. Upon arrival, the participants were randomly assigned a role. One participant played the expert role, and the other participant played the technician role. This randomization helps reduce any potential bias because of participants' personalities or preferences. Each participant was arranged to perform their tasks in a different room. The two rooms are soundproofed and simulate different offices or locations. The layout of the laboratory is shown in **Figure 2**.



Note: Cam = Camera

Figure 2. Layout of Laboratory

A partial within-subjects design was adopted for this experiment. Participants were randomly assigned to one of the four task combinations. The four task combinations consisted of two different experiment conditions, incorporating two different sequences to complete the tasks. In the experiment conditions, all teams performed one task in the videoconferencing and one task with the MR technology. Task complexity was also varied, but the effect of complexity was not within the scope of this thesis[1]. The first experiment condition, named CT1, involved a lower complexity task communicated via videoconferencing, followed by a higher complexity task

[1] The effect of complexity is analyzed in the PhD student's thesis.

communicated via MR technology. The second experiment condition, referred to as CT2, involved a lower complexity task communicated via MR technology, followed by a higher complexity task communicated via videoconferencing. The reversed sequences of the first experiment condition, named CT1R, and the reversed sequences of the second experiment condition, namely CT2R, feature the same experiment conditions but with the tasks presented in the opposite order. Arrangement of such reversal was aimed at canceling the learning effect, sequential effect, and other biases that may arise from the order in which the tasks and technologies were presented, ensuring that any differences observed in the performances can be attributed to the medium of the communication employed during the sections instead of the sequences of the tasks or technologies. The experimental conditions for the task complexity and communication technology are shown in **Table 3**.

Table 3. Experimental Conditions for Task Complexity and Communication Technology

Condition	Task 1	Communication Technology (Task 1)	Task 2	Communication Technology (Task 2)
CT1	Lower Complexity	Videoconferencing	Higher Complexity	MR technology
CT1R	Higher Complexity	MR technology	Lower Complexity	Videoconferencing
CT2	Lower Complexity	MR technology	Higher Complexity	Videoconferencing
CT2R	Higher Complexity	Videoconferencing	Lower Complexity	MR technology

To make sure that every participant had a basic knowledge and experience with the two technologies and their functionality, training was provided to both experts and technicians for each technology. Two trainings were the same and were undertaken before each task. This is to ensure that the effect of unfamiliar technology would be minimized.

Before the experiment and after completing each task, participants were asked to fill out a self-administered questionnaire.

4.2 Participants

Recruitment of participants took place on the Panelfox screening platform that HEC Montreal employs. The platform has a diversified pool of potential participants, which ensures a broad representation of demographics and backgrounds, therefore the source of participants is more generalized. Invitation emails were distributed by the platform to the users registered in the system. The email outlined the study objectives, provided brief descriptions of the experiment, noted a duration of 1.5 hours, and specified the compensation type. The inclusion and exclusion criteria were also highlighted in the email.

The inclusion criteria were:

- Be 18 years of age or older.
- Have a sufficient oral and written English level to read documents and communicate with other participants on the assigned group work.

The exclusion criteria were:

- Individuals with visual health problems (except for corrective glasses).
- Individuals with motion sickness.
- Individuals with pacemakers or other implanted medical devices.
- Individuals who suffer from migraine.
- Individuals who suffer from balance disorders.
- Individuals who suffer from epilepsy.

Interested potential participants had to complete a screener questionnaire to confirm that they met the criteria. After passing the questionnaire, participants were then given a list of experiment time slots to choose from.

In this study, a total of 35 experiment sessions took place, which consisted of a total of 70 participants. To ensure the validity of the results, we excluded data from participants who exhibited a language barrier or who did not follow the instructions given in the experiment. After carefully reviewing the data, we decided to remove 3 sets of data involving 6 participants from the final analysis because the abovementioned issues were identified. As a result, the final analysis was based on 32 sets of data collected from 64 participants.

In this study, the participant had to provide their consent for the data collection before we could start the experiment. This study received approval from the school's Ethics Research Committee under project number #2025-5960, led by the principal researcher Edward Opoku-Mensah, PhD student, with me participating as a team member.

4.3 Instruments

Digital Meetings Laboratory at HEC Montréal. The Laboratory is well-equipped with two experimental rooms. Both rooms are soundproof. The experimental rooms also meet all the experiment requirements.

Video and audio capturing device. Each study room in the laboratory was equipped with 3 Pan-Tilt-Zoom cameras to capture participant behaviors, and a microphone mounted to the ceiling to record their conversations.

Smartphone with videoconferencing application. For the videoconferencing remote assistance task, we used an iPhone 14 Pro Max with Teams application as the communication technology.

Mixed reality device with annotating videoconferencing application. For the MR technology remote assistance task, a Microsoft HoloLens 2 with Kognitiv Spark's RemoteSpark application was used as the communication technology.

Three-dimension printer with accessories. In this experiment, the Creality Ender 3 V3 SE 3D Printer was used in the technician room.

Display screens. Two screens were in the expert room for displaying printer accessory legend and live video captured by technician respectively.

Tablet computers. One iPad in the expert room and one iPad in the technician room were being used for the pre-task questionnaire and the post-task questionnaires.

Laptop computers. A Dell notebook was used in the expert room for the procedure manual.

Pointing device. A computer mouse was used in the expert room for annotation during remote assistance sessions with MR technology.

4.4 Data Collection and Measurements

In this section, a list of measurements used throughout the experiment will be shown. Since user communication is affected by the remote assistance technology, to understand and follow observed events associated with the use of the technology, it is particularly important to collect both qualitative and quantitative data. This explores the various classes of behaviors of both the expert and technician in connection with the communication technology being used. Therefore, both quantitative and qualitative approaches were adopted.

4.4.1 Quantitative Approach

The self-administered questionnaire was employed to collect participants' demographics and data that represent participants' experiences and perceptions. The User Experience Questionnaire (UEQ) is reliable for measuring users' perceptions in the user experience aspect (Schrepp et al., 2017a). A short version of UEQ (Schrepp et al., 2017b) can be used to measure perceived usefulness (Meiners et al., 2024) and supportiveness for interactive technologies. Therefore, we utilized these questions to collect the user perspective data after each task. These self-reported user perceptions and experiences are the quantitative data that can be analyzed to provide insights on how different communication technologies influence user experience for experts and technicians respectively.

Participants' Demographics: Before the tasks, participants had to complete a demographic questionnaire. The age group, gender, level of education, specialization of education, level of skill in operating augmented reality applications on mobile phones, level of skill in operating MR technology devices, and experience of operating 3D printers were collected.

Supportiveness of Communication Technology: Immediately after each task, participants were asked to rate how supportive they consider the communication technology is to work on their tasks ("The technology supported me in performing the task"). A 7-point Likert scale was utilized to gauge their responses, allowing a nuanced understanding of how experts and technicians felt about the supportiveness of the technology being used in the task they just completed.

Users Perceived Usefulness: Participants were asked to rate their perceived usefulness of the communication technology used right after each task ("The technology was useful for me to do the task"). A 7-point Likert scale was also utilized. This rating aimed to capture participants' subjective assessment of how useful they think it is in the remote assistance session.

4.4.2 Qualitative Approach

Throughout the experiment tasks, video and audio recordings were collected for direct observations. In this way, participants' real-time communication and behavior can be analyzed. Careful measurements were undertaken to manually observe the participant from video playback, to identify and code for the events of corrective instruction, uncorrected visual misalignment, unconscious body interpretations, and situational unawareness.

Corrective instruction: In this experiment, we refer this to the frequency of instruction to reposition the technician's view. This tracks how often the expert needs to explicitly request the technician to adjust their MR technology device or videoconferencing device to get a better view of the problem. These requests reflect disrupted workflow, as the expert cannot see the full picture in front of the technician, therefore time might be wasted, and frustration may be aroused for the expert. We keep a count whenever the experts ask the technicians to adjust their view or angle for better visualization of the 3D printer.

Uncorrected visual misalignment: In this experiment, we refer this to the frequency of camera misalignment. Camera misalignment happens when the camera is not capturing the relevant object or area that the technician is referring to. This tracks the instances where the view of the MR technology device or videoconferencing device does not align with the technician's verbal descriptions or the area they are currently working on. Such misalignment may lead to confusion, misinterpretations, delays, and misunderstandings in communications, and therefore create frustration for the expert. We document each instance of camera misalignment that occurs during the tasks.

Unconscious body interpretations: In this experiment, we refer this to the frequency with which the experts had to use hand gestures while explaining the steps, even though the gesture was not conveyed. Hand gestures are ineffective when the technician cannot see in remote settings. However, when the expert faces difficulties conveying instructions, demonstrating procedures, or expressing directions to the technician, they will make hand gestures unconsciously. This may reflect frustration for both the expert and the technician, which could possibly be eliminated by using the drawing tool if such technology is available. We count the instances when experts use hand gestures during communication.

Situational unawareness: In this experiment, we refer this to the frequency that experts are pausing the instructions due to not being able to view the equipment status, such as the message displayed on the screen of the 3D printer. Limited views can lead to delays in troubleshooting, as the expert may require additional information or clarification that could be easily observed with a broad view. This may impact task flow and create frustration. We take a count when the expert's actions were on hold because the MR technology device or the videoconferencing device cannot clearly capture the status of the printer.

With the result being gathered, we can construct the quantitative data accordingly for further analysis.

4.5 Procedure

Participants were instructed to arrive at the Digital Meeting Laboratory in HEC Montreal. Once the participants arrived at the laboratory, they were welcomed and randomly assigned a room number, which would determine the role they would be playing. The participant who acted as a technician used study room 1. The participant who acted as an expert used study room 2. They were then advised to go to the washroom if needed, followed by leaving their personal belongings in a designated area and turning their mobile phone to silence mode. Participants then entered their rooms respectively.

Before starting the data collection, a standard introduction was read to describe the study. After that, participants were given 2 copies of the consent form for them to read and sign.

After confirming that we had the consent, they were instructed to do a pre-task questionnaire on iPad. After they finished the questionnaire, we provided them with the mental rotation test[2]. They were given instructions on how to do it and were given an additional 5 minutes to study and practice with the example questions. After that, they were given 3 minutes to complete this 12-question test.

After the mental rotation test, the expert was brought to the technician room. A 3D printer was placed on the desk in front of the technician. According to the counterbalance implementation, the first communication technology (Videoconferencing by iPhone or MR technology by Hololens) would be introduced to both the technician and the expert. Both participants were informed that the expert would instruct the technician on how to operate the 3D printer via the communication technology given. With both the expert and technician present, a standardized tutorial was given to the technician for the usage of the communication technology. To ensure their familiarity with the communication technology, they had to perform a training first, before doing Task 1 of the experiment. The expert was brought back to the expert room and both the door of the technician room and the expert room were closed for soundproofing.

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[2] The mental rotation test is intended for analysis in the PhD student's thesis.

The expert received a standardized tutorial in the expert room on how to operate the printer and how to use the communication technology to guide the technician in operating the 3D printer. On the left screen on the wall, a picture with the legends of the tools to be used with the 3D printer was displayed. On the right screen on the wall, the video captured by the technology in the technician room was displayed. A training guide containing the operation steps for the 3D printer was displayed on the laptop and the contents were explained to the expert step by step. This training guide was available for the expert throughout the training.

After the tutorials, the recording was started when both participants were ready. Both room doors were closed when the training started. The expert instructs the technician according to the training guide. After the training finished, both doors were opened, and participants were asked to fill out a post-training questionnaire.

When participants finished the questionnaire, both doors were closed, and a tutorial was then given to the expert for Task 1. A task guide containing the operation steps for the 3D printer was displayed on the laptop. The contents were explained to the expert, and the guide was available throughout the task for the expert's reference. Task 1 started when both participants were ready. The expert would instruct the technician according to the task guide. After task 1 finished, both doors were opened, and the participants were asked to fill out a post-task questionnaire.

After they finished the post-task questionnaire, we changed the communication technology and reset the 3D printer.

The expert was brought to the technician room again, and a tutorial was given to the technician for the usage of the second communication technology. Then, the expert was brought back to the expert room, and both doors were closed again. A tutorial was then given to the expert on the communication technology and the training procedure. This training was the same as the training before Task 1. This process ensured that both participants were familiar with the use of the communication technology. The training guide was displayed on the laptop for the expert throughout the training.

Training started when both participants were ready. The expert would instruct the technician according to the training guide. After the training finished, doors were opened, and both participants were asked to fill out a post-training questionnaire.

After that, room doors were closed and instruction was then given to the expert for Task 2. The task guide for task 2 was displayed on the laptop. Operation steps were explained to the expert. This guide was available throughout the task for the expert's reference. Task 2 started when both participants were ready. The expert would instruct the technician according to the task guide. After Task 2 finished, both participants were asked to fill out a post-experiment questionnaire.

At the end of the experiment, a standardized closing script was read and a compensation form was given to them to fill out. We also advised the participants not to disclose the experiment context to other people to avoid bias.

The procedure diagram is shown in **Figure 3**.

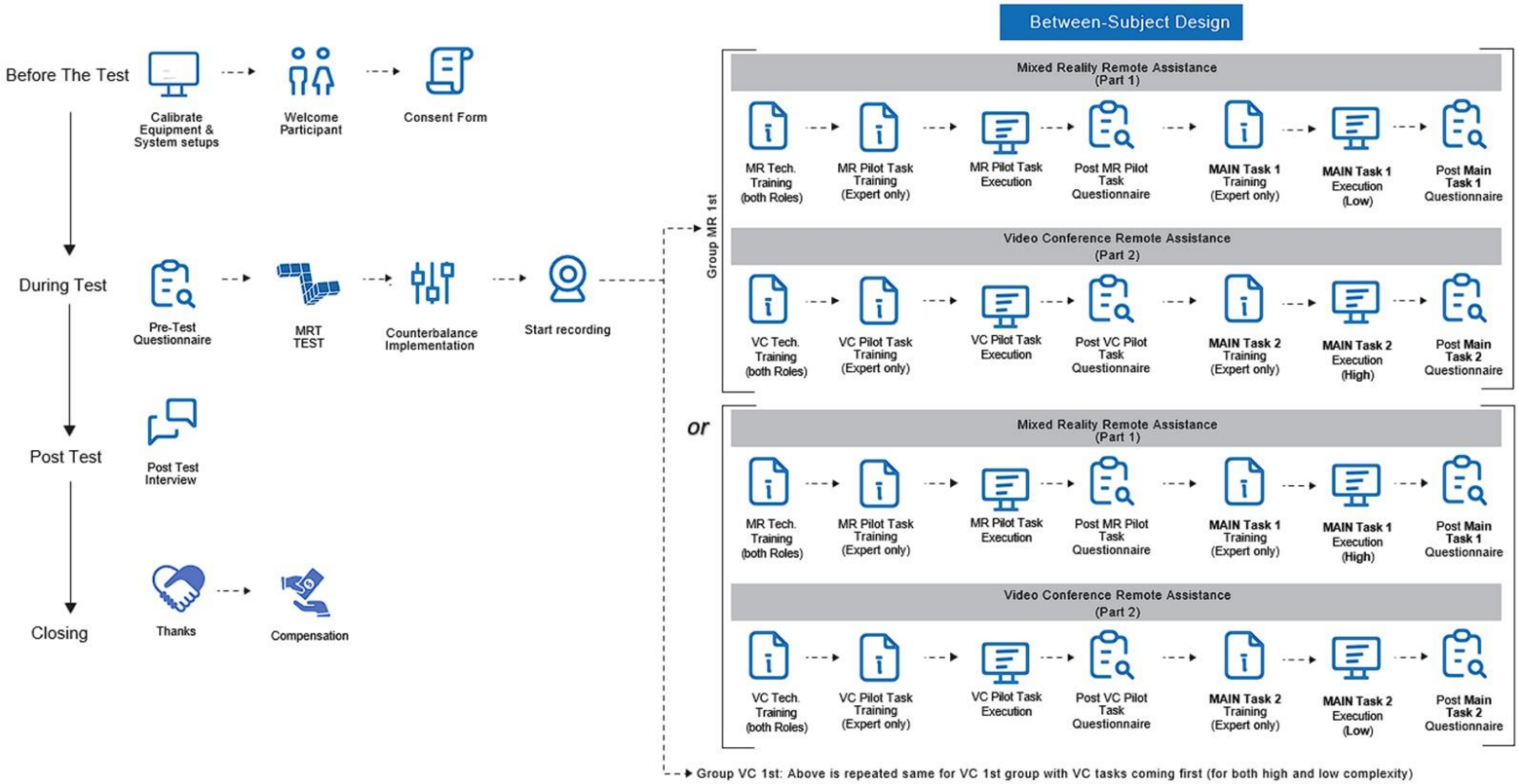


Figure 3. Procedure Diagram

Credit: Principal researcher Edward Opoku-Mensah, PhD Student.

4.6 Analysis Strategy

The analysis of data aimed to verify the hypothesis as well as to explore the possibility of further study by examining the phenomenon found during the experiment. The occurrences of each behavior in H1, H2, H3, and H4 were quantified by going through all the tasks in the recordings, and the data from the questionnaires were organized and analyzed for H5 and H6. These data were also aggregated with the user behavioral data and then compiled for assessment using statistical methods to determine if there was any significance in the findings. For each hypothesis, a T-test was run to compare the values of all dependent variables. To assist in the analysis of the responses, the SAS online platform was used.

Chapter 5: Analysis and Results

This chapter will present the results obtained from the experiment and lay out the analysis process. Data collected will be analyzed according to our study hypotheses. Section 5.1 is the descriptive analysis of the results. Section 5.2 examines the findings related to the relationship between user behavior and the communication technology used in the experiments. Section 5.3 focuses on the comparison of users' perspectives between the role of expert and technician in remote assistance sessions using different communication technologies, based on the results collected from the questionnaires.

5.1 Descriptive Analysis

5.1.1 Description of Participants

In this study, we recruited 70 participants who formed 35 pairs of experts and technicians (assigned randomly). We utilized 64 participants' data from 32 remote assistance sessions for our analysis, while data from the other 6 participants was excluded due to language or instruction comprehension difficulties.

Among our sample size of 64 participants, 25 were male and 39 were female. 53.1% of the participants were 25-34 years old, 26.6% were between 18-24 years old, 14.1% were 35-44 years old, and the remaining 6.2% were 45 years old and over. Regarding education, 53% of the participants had a Master's degree, 32% of them had a Bachelor's degree, 6% had a PhD, and 6% were below the undergraduate level. We had 28% of participants specialized in Information Technology and related programs, 14% in Management and related programs, 12% specialized in Marketing, 11% in Finance, and the remaining were from other disciplines. Statistics of demographic data are summarized in **Table 4**.

Table 4. Demographic Statistics

Baseline characteristic (n=64)	Frequency	Percentage
Gender		
Male	25	39.1%
Female	39	60.9%
Age		
18-24 years old	17	26.6%
25-34 years old	34	53.1%
35-44 years old	9	14.1%
45-54 years old	2	3.1%
55 years and over	2	3.1%
Education		
CEGEP / College	4	6.3%
Bachelor’s	21	32.8%
Master's	34	53.1%
Ph.D.	4	6.3%
Other	1	1.6%
Specialization		
Accounting	4	6.3%
Design	1	1.6%
Economy	1	1.6%
Engineering	4	6.3%
Finance	7	10.9%
Health	3	4.7%
Human Resources	2	3.1%
Information Technology (Computer Science, Data Science, Information System, Software Engineering, User Experience)	18	28.1%
Law	1	1.6%

Logistic	4	6.3%
Management (Business Administration, Business Intelligence, Business Management, International Business, Project Management)	9	14.1%
Marketing	8	12.5%
Psychology	1	1.6%
Other	1	1.6%

5.1.2 Descriptive Statistics

The descriptive statistics of all variables (see **Table 5**) measured for user behaviors show the mean, standard deviation, minimum, medium, and maximum of all 64 experiment tasks regarding participants' correctional communications, uncorrected visual misalignment, unconscious body interpretations, and situational unawareness. This data was collected by measuring the actual frequency of occurrence.

When examining the descriptive statistics of participants' user behaviors, the highest frequency of occurrence observed is the correctional communications measured in both communication technologies. The mean of 3.094 and the standard deviation of 2.401 for MR technology, which is higher than the mean of 2.938 and the standard deviation of 1.999 for videoconferencing. In contrast, the mean, standard deviation, and maximum frequency of occurrence for uncorrected visual misalignment, unconscious body interpretations, and situational unawareness are all lower with the usage of MR technology than those with the usage of videoconferencing.

Table 5. Descriptive Statistics for User Behaviors in Experiment Tasks

Technology	Variable	N	Mean	Std Dev	Minimum	Median	Maximum
MR technology	Correctional communications	32	3.094	2.401	0.000	2.000	11.000
	Uncorrected visual misalignment	32	0.313	0.738	0.000	0.000	3.000
	Unconscious body interpretations	32	1.250	1.391	0.000	1.000	5.000
	Situational unawareness	32	0.344	0.653	0.000	0.000	2.000
Videoconferencing	Correctional communications	32	2.938	1.999	0.000	2.000	8.000
	Uncorrected visual misalignment	32	0.688	1.447	0.000	0.000	6.000
	Unconscious body interpretations	32	2.500	2.314	0.000	2.000	10.000
	Situational unawareness	32	0.781	1.362	0.000	0.000	6.000

The descriptive statistics of all variables (see **Table 6**) for user perception show the mean, standard deviation, minimum, medium, and maximum of all 64 participants regarding participants' perceived supportiveness and perceived usefulness. All participants rated their perceived supportiveness and perceived usefulness on a 7-point Likert scale.

When looking at the descriptive statistics of user perception from participants, we found that the rating for MR technology, with the mean values ranging from 5.531 to 6.313 and the standard deviations between 1.120 and 1.481, is higher than the rating for videoconferencing, which has the mean values ranging from 5.219 to 5.469, and the standard deviations from 1.436 to 1.578.

Furthermore, we also found that experts rated MR technology higher for both supportiveness (mean of 6.219 and standard deviation of 1.128), and usefulness (mean of 6.313 and standard deviation of 1.120). Whereas technicians rated supportiveness (mean of 5.531 and standard deviation of 1.481), and usefulness (mean of 5.719 and standard deviation of 1.397) lower than experts.

Table 6. Descriptive Statistics for User Perceptions of Participants

Technology	Variable	N	Mean	Std Dev	Minimum	Median	Maximum
MR technology	Expert perceived supportiveness	32	6.219	1.128	3.000	7.000	7.000
	Technician perceived supportiveness	32	5.531	1.481	1.000	6.000	7.000
	Expert perceived usefulness	32	6.313	1.120	3.000	7.000	7.000
	Technician perceived usefulness	32	5.719	1.397	2.000	6.000	7.000
Videoconferencing	Expert perceived supportiveness	32	5.344	1.578	1.000	6.000	7.000
	Technician perceived supportiveness	32	5.219	1.560	2.000	6.000	7.000
	Expert perceived usefulness	32	5.250	1.524	1.000	5.500	7.000
	Technician perceived usefulness	32	5.469	1.436	2.000	6.000	7.000

5.2 Communication Technology and User Behavior

The primary objective of this analysis is to determine if there was any statistically significant difference in the specific behaviors between the two communication technologies. Each of the concerned behaviors is investigated separately as the dependent variable, whereas the independent variable is the communication technology being utilized. This allows for a clear understanding of how each technology impacts user interaction. The T-test is specified for comparisons involving two groups, making it a suitable statistical instrument for this analysis. Since participants were not exposed to all experiment conditions, each observation is considered independent. We also assumed that the data collected in different experiment tasks were approximately normally distributed, which is essential for the validity of the T-test results. Therefore, for the 4 hypotheses relating to user behaviors, we conducted separate independent T-tests to compare the means of the dependent variable across the different communication technologies.

5.2.1 Effects of communication technology on correctional communications (H1)

The first hypothesis concerns how communication technology would influence the frequency of correctional communications in the visual field. It was predicted that MR technology would result in fewer correctional communications from the experts regarding the visual field. The null hypothesis proposed that no difference was found, which suggested that the frequency of correctional communications exhibited by the group using MR technology was equivalent to those using videoconferencing. Whereas the alternative hypothesis suggested a difference where the frequency of correctional communications exhibited by the group using MR technology was less than those using videoconferencing.

For H1, the left-tailed T-test results (See **Table 7**) indicated that the p-value is 0.6109 ($t=0.28$, $DF=62$). With such a high P-value, the difference between the frequency of the two communication technologies is not statistically significant. For this hypothesis, the data failed to reject the null hypothesis. As a result, H1 is not supported in this research.

Table 7. H1 Significant Assessment: Left-tailed T-test results

Variable	DF	t Value	Pr < t	Hypothesis Supported?
Correctional communications	62	0.28	0.6109	No

5.2.2 Effects of communication technology on uncorrected visual misalignment (H2)

The second hypothesis is regarding the effect of communication technology on the frequency of uncorrected visual misalignment. It was projected that MR technology would result in fewer visual misalignments which were left uncorrected. Null hypothesis propositioned that no difference was found, which suggested that the frequency of uncorrected visual misalignment exhibited by the group using MR technology was equivalent to those using videoconferencing. The alternative hypothesis, on the other hand, posited a difference in which the frequency of uncorrected visual misalignment exhibited by the group using MR technology was less than those using videoconferencing.

The left-tailed T-test results for H2 (See **Table 8**) indicated that the p-value is 0.0981 (t= -1.31, DF=62). At the significance level of 10%, we find that the p-value is marginally significant, and we can consider this result as providing enough evidence to reject the null hypothesis. Therefore, H2 is supported in this experiment.

Table 8. H2 Significant Assessment: Left-tailed T-test results

Variable	DF	t Value	Pr < t	Hypothesis Supported?
Uncorrected visual misalignment	62	-1.31	0.0981	Yes

5.2.3 Effects of communication technology on unconscious body interpretations (H3)

The third hypothesis is about the impact of communication technology on the frequency of unconscious body interpretations. It was proposed that MR technology would result in fewer unconscious body interpretations by the experts during a remote assistance session. The null hypothesis posited that there is no significant difference between the two groups, which suggested that the frequency of unconscious body interpretations exhibited by the group using MR technology was comparable to those using videoconferencing. The alternative hypothesis asserts that the frequency of uncorrected visual misalignment exhibited by the group using MR technology was less than those using videoconferencing.

For H3, the left-tailed T-test results (See **Table 9**) indicated that the p-value is 0.0055 (t= -2.62, DF=62). This result is statistically significant, indicating strong evidence to reject the null hypothesis. As a result, H3 is supported by the data.

Table 9. H3 Significant Assessment: Left-tailed T-test results

Variable	DF	t Value	Pr < t	Hypothesis Supported?
Unconscious body interpretations	62	-2.62	0.0055	Yes

5.2.4 Effects of communication technology on situational unawareness (H4)

The fourth hypothesis addresses the influence of communication technology on the frequency of situational unawareness during communication. It was suggested that MR technology would result in fewer occasions of situational unawareness during a remote assistance session. The null hypothesis posited that there are no statistical differences between the two groups, which means that the frequency of situational unawareness exhibited by the group using MR technology was similar to those using videoconferencing. The alternative hypothesis posits that the frequency of situational unawareness exhibited by the group using MR technology was less than those using videoconferencing.

For H4, the left-tailed T-test results (See **Table 10**) indicated that the p-value is 0.0531 (t= -1.64, DF=62). This p-value is significant at the 10% significance level, which provides stronger evidence for us to reject the null hypothesis. H4 is therefore supported in the study.

Table 10. H4 Significant Assessment: Left-tailed T-test results

Variable	DF	t Value	Pr < t	Hypothesis Supported?
Situational unawareness	62	-1.64	0.0531	Yes

5.3 Communication Technology and User Perception

This evaluation is to determine if there were any statistically significant differences in the user perception between the two communication technologies when interacting as an expert and a technician. The investigation focuses on two areas, including perceived supportiveness and usefulness. As the data was collected from two different roles, it would be interesting to explore if users' perceptions varied as well by running the analysis on the collected data separately. This approach will allow for a more detailed understanding of how different roles of the users perceive the use of communication technologies. Since every collection was independent, and we assumed that the ratings collected from the participants followed a normal distribution, the T-test is considered a suitable tool for running the analysis. Therefore, for each of the 2 hypotheses relating to user perceptions, we conducted separate independent T-tests for data collected from different roles, to compare the means of the dependent variable across the different communication technologies.

5.3.1 Effects of communication technology on perceived supportiveness (H5)

The fifth hypothesis concerns how users perceived the supportiveness of different communication technologies being used in remote assistance tasks. It was predicted that MR technology would be more supportive to the users than videoconferencing. The null hypothesis proposed that no difference was found, which suggested that the perceived supportiveness regarding MR technology and videoconferencing was equivalent. Whereas the alternative hypothesis suggested a better supportiveness with the usage of MR technology than the usage of videoconferencing.

For H5, 2 right-tailed T-tests were run for data from experts and technicians respectively. Analysis results for experts' data (See **Table 11**) indicated that the p-value is 0.0066 (t=2.55, DF=62). From the perspective of experts, this statistically significant result implied that received supportiveness of MR technology is indeed greater than that of videoconferencing, providing us strong evidence to reject the null hypothesis.

Table 11. H5 Significant Assessment: Right-tailed T-test results for expert

Variable	DF	t Value	Pr > t	Hypothesis Supported?
Expert perceived supportiveness	62	2.55	0.0066	Yes, from the perspective of experts

Analysis results for technicians' data (See **Table 12**) indicate that the p-value is 0.2072 (t=0.82, DF=62). From the perspective of technicians, the results implied that there is insufficient evidence to reject the null hypothesis, indicating their perception of supportiveness does not significantly favor MR technology over videoconferencing.

Table 12. H5 Significant Assessment: Right-tailed T-test results for technician

Variable	DF	t Value	Pr > t	Hypothesis Supported?
Technician perceived supportiveness	62	0.82	0.2072	No, from the perspective of technicians

Due to the separate analysis by role, it can be concluded that H5 is partially supported. More precisely, H5 is supported in the expert subgroup but not in the Technician subgroup.

5.3.2 Effects of communication technology on perceived usefulness (H6)

The sixth hypothesis is about how users perceived the usefulness of different communication technologies being used in remote assistance tasks. It was suggested that MR technology would be more useful to the users than videoconferencing. The null hypothesis posited that no difference was found between the two groups, suggesting that the perceived usefulness of MR technology was equivalent to that of videoconferencing. The alternative hypothesis, on the other hand, proposed that it is more useful for MR technology than for videoconferencing.

For H6, we ran 2 right-tailed T-tests for the data collected from experts and technicians respectively. Analysis results for experts' data (See **Table 13**) show that the p-value is 0.0012 (t=3.18, DF=62). From the perspective of experts, this p-value shows a statistically significant result, which indicates that the experts perceived MR technology to be more useful than videoconferencing, allowing us to reject the null hypothesis with strong evidence.

Table 13. H6 Significant Assessment: Right-tailed T-test results for expert

Variable	DF	t Value	Pr > t	Hypothesis Supported?
Expert perceived usefulness	62	3.18	0.0012	Yes, from the perspective of experts

Analysis results for technicians' data (See **Table 14**) show that the p-value is 0.2415 (t=0.71, DF=62). From the perspective of technicians, the results indicated that the data does not have significant evidence to reject the null hypothesis, which implied that their perception of usefulness is not significantly higher for MR technology than videoconferencing.

Table 14. H6 Significant Assessment: Right-tailed T-test results for technician

Variable	DF	t Value	Pr > t	Hypothesis Supported?
Technician perceived usefulness	62	0.71	0.2415	No, from the perspective of technicians

Considering the circumstances of subpopulations, at this stage, it can be concluded that H6 is partially supported. More specifically, H6 is supported in the expert subgroup but not in the technician subgroup.

5.4 Summary of Hypothesis Results

The results of six hypotheses testing the impact of communication technology (MR vs. videoconferencing) on both user behaviors and perceptions is summarized in **Table 15**. Each hypothesis was evaluated using independent T-tests, revealing which differences were statistically significant across behavior types and user roles.

Table 15 Communication Technology Effects on User Behavior and Perception

Hypothesis	Variable	Conclusion
H1	Correctional Communications	Not supported (no significant difference)
H2	Uncorrected Visual Misalignment	Supported (MR → Fewer misalignments)
H3	Unconscious Body Interpretations	Supported (MR → Fewer unconscious gestures)
H4	Situational Unawareness	Supported (MR → Fewer pauses due to lack of visibility)
H5	Perceived Supportiveness	Supported for experts (MR perceived as more supportive) Not supported for technicians (no significant difference)
H6	Perceived Usefulness	Supported for experts (MR perceived as more useful) Not supported for technicians (no significant difference)

5.5 Post-Hoc Observations

During the analysis, two differences in behavior that were not hypothesized emerged. One recurrent behavior was noted among experts during the experiments. Experts tend to repeat their instructions more in videoconferencing. In the observation, we found that technicians were busy holding the camera and therefore their execution of the instruction was obstructed or slowed. Experts were either often being asked to repeat their guidance, or they repeated it multiple times spontaneously to ensure that technicians could follow along effectively.

The behavior of requesting for repeating instructions aligns with the tenets of Cognitive Load Theory (Sweller, 1988), which suggests multitasking can induce cognitive overload, and therefore technicians struggled to process the information given in a single exposure. The challenges posed by multitasking in videoconferencing settings also mean that there was a higher cost of grounding in communication as well (Clark & Brennan, 1991). In this case, the technicians needed extra effort to understand the context of the instruction, and the experts did not get a response from the technician confirming their acknowledgment or understanding, therefore they had to spend extra effort to repeat themselves to ensure the message had been delivered successfully. It is a sign of a higher reception cost from technicians and a higher formulation cost from experts for a grounding in communication. Repairing of information and repeating of information during communication can negatively impact user experience (Narayanamma et al., 2024).

In the experiments, we also observed that some participants with considerably wide eyeglass frames would experience visual misalignments that were corrected by the experts. On repeated occasions, we found that the technicians' eyeglasses kept pushing the Hololens upward, which caused the camera on it to point up, therefore resulting in a misalignment of vision. Most of the misalignments were corrected by the experts. The expert would often need to make a request to correct the vision by asking the technicians to tilt their heads or adjust the device. This caused interruptions during the tasks and frustrated both the experts and technicians.

Meanwhile, those without wide eyeglass frames also experienced incorrect vision alignments. Though much less frequent than those with eyeglasses, their vision of the Hololens would still occasionally be shifted upward. Technicians would push the device when it was not tight enough, or when it was displaced because they moved their head, which affected the camera angle. They would also adjust the device because it was uncomfortable or to better fit with their hairstyle. These actions affected the angle of the camera on the MR technology device, which subsequently resulted in extra communication for the corrections and affected user experience.

Chapter 6: Discussion

The analysis results will be discussed in detail in this chapter, highlighting the key findings in relation to the two research questions. The implication of the analysis will be explored, providing insights into how user behavior and user perception vary among different communication technologies being adopted. Beyond our primary hypotheses, we will also discuss the unanticipated observations regarding some additional user behavior patterns influenced by MR technology, and the different perceptions of MR technology's application among different roles (expert vs. technician).

6.1 Communication Technology and User Behavior

In the first research question, we were trying to answer how mixed reality technology influences communication behavior during remote assistance tasks compared to videoconferencing. According to the analysis of the quantified user behaviors, H2, H3, and H4 are supported. H1, however, is not supported. This indicates that there was not enough evidence to demonstrate that MR technology reduces correctional communications. However, MR technology does reduce uncorrected visual misalignment, unconscious body interpretations, and situational unawareness during remote assistance sessions. These findings suggest that while MR technology may not directly influence the frequency of correctional communications, it significantly enhances visual alignment and contextual awareness, demonstrating that it better supports the communication grounding process during remote assistance.

By observing the interactions between and behaviors of experts and technicians during the experiment, we were able to identify specific patterns that highlight the advantages of MR technology. These patterns reveal that users exhibit less distractive communication behavior and better user experience when utilizing MR technology, as they facilitate a more immersive experience that bridges the gap between physical and virtual environments. From the communication grounding point of view, MR technology seems to lower the costs of grounding in terms of formulation costs, reception costs, understanding costs, display costs, fault costs, and repair costs.

From the post-hoc observations, we discovered that the MR technology device was misaligned due to various reasons, including technicians' eyeglasses, user habits, comfort issues, hair styling, and displacement due to head movements. MR technology misalignment occurred frequently during the tasks and on many occasions the experts had to raise their concerns as they could not see the object they were working on. This may be why the frequency of correctional communications remained high, as technicians struggled to maintain proper visual alignment during their tasks. As a result, we did not see a significantly lower frequency of correctional communications with the use of MR technology compared to videoconferencing.

From the analysis, we could see that there were fewer uncorrected visual misalignments exhibited during the remote assistance sessions by MR technology compared to videoconferencing. This would mean a lower potential repair cost for the communication grounding because errors tend to snowball into larger issues (Clark & Brennan, 1991). The reduction of uncorrected visual misalignment contributed to a smoother and more intuitive user experience, allowing experts to focus on the task rather than struggling with discrepancies between what they saw and technicians' actions or descriptions. While the p-value of uncorrected visual misalignments is marginal, the result is still promising as it still indicates a significant difference. Correctional communications have a high p-value, suggesting frequency of correctional communications was not found to be significantly associated with the use of MR technology.

During the experiment, we found a decrease in hand gestures that were being made by the experts during MR technology sessions. This reflects that the display cost during communication grounding from experts is notably reduced. Previous research has also shown that the reduction of hand gestures reflects lower cognitive load during communication (Clark & Krych, 2004) as it was easier to convey instructions verbally. This may mean experts are more supported by the MR technology through the annotation function offered by MR technology. Instead of trying to convey complex information that causes unintentional physical movement, MR technology streamlines the interaction process by allowing experts to focus on delivering instructions via visual aids, which enhances the overall clarity of the content. The shift in communication style not only improves the engagement between experts and technicians but also facilitates a deeper understanding among them, as they can better convey and absorb complex concepts of the tasks rather than relying solely on verbal explanations. With the annotation being seen by the technician during communication, the technician's understanding cost of the grounding is also lowered. Technicians can execute their tasks with greater confidence, leading to increased efficiency and reducing the chance of errors and misunderstandings.

The data collected also reveals a significant reduction in situational unawareness in MR technology remote assistance sessions. Situational unawareness happens when the technician's equipment exhibits a change of status, yet both the expert and technician remain unaware of it, causing a disruption in the workflow or errors. This would introduce a high fault and repair cost for communication grounding. With the use of videoconferencing, it is often that the instrument changes its status but either the change is outside of the field of view of the technician's camera which caused the expert to miss it, or the technician is too busy managing the camera and missed the change, or both scenarios happen simultaneously. With MR technology, experts have a broad and real-time vision of the equipment and therefore can stay informed about instant changes, allowing for quicker adjustments and more effective support during remote assistance sessions. Therefore, fault and repair costs are lowered.

Another post-hoc observation that emerged from the experiments was the repeated instructions by experts during videoconferencing sessions. When technicians needed to manually hold and adjust the camera while communicating and working on the tasks, their ability to follow the expert's instructions in real-time was obstructed or delayed. Therefore, experts had to repeat their guidance multiple times, with or without technicians' requests. The frequent repetition of instructions increased the communication grounding costs. These increased grounding costs may be related to the limitations of videoconferencing in remote assistance and suggest another potential value of MR technologies. MR technology that leaves the technician's hands free could help tackle communication challenges by lowering both reception and production costs in grounding. However, since this behavior is not within the scope of the current study, further research is needed to explore the statistical significance between the use of communication technology and repeated instructions.

6.2 Communication Technology and User Perception

The second research question focuses on how user perception varies between mixed reality technology and videoconferencing in Remote Assistance Tasks. According to the findings from the analysis, H5 and H6 are partially supported. The main discrepancies observed between the results in the hypothesis were related to the subgroup within the population. The original hypothesis did not separate users into different groups according to their role. We assumed all users would have a similar user perception towards MR technology and videoconferencing. However, interesting findings were discovered during the analysis. Variation was found based on different user roles as technicians and experts.

Our results indicate that the experts perceived MR technology to be more useful than videoconferencing, which suggests that they thought MR technology was more effective in assisting them in communicating and completing the task. They also feel more supported by the MR technology during remote assistance sessions, suggesting they feel that it is more beneficial to use the technology for their task. The P-values for both supportiveness and usefulness from experts are very low, indicating that the difference between MR technology and videoconferencing is very significant.

It may be that the reduction of correctional communications by the experts is the contributing factor to the better user experience provided by MR technology. The lower frequency of unconscious hand gestures also proves that the annotation function of the MR technology better supports the expert when they provide instructions. Without having to spend effort on correction or clarification, experts can focus more on delivering clear and concise instructions. This shift in focus ultimately leads to improved efficiency and effectiveness in remote assistance, as experts can engage more deeply with the tasks at hand, resulting in quicker task resolution and higher satisfaction.

In contrast, the technicians' perspectives did not align with the experts. Technicians do not consider MR technology to be significantly more useful than videoconferencing, nor do they consider MR technology to be more supportive in their tasks. The high p-value for both usefulness and supportiveness from the data of technicians indicates that the MR technology is not perceived as an enhancement tool in user experience for this role.

One of the reasons for this may be the multiple adjustments on the MR technology device that need to be made by the technician during the tasks in this research. Misalignment issues are the factors that significantly hindered their ability to engage in the operations effectively. The extra cognitive load due to the need to constantly adjust the MR technology device and the high communication grounding cost due to the repair communications may have resulted in the perception that the MR technology is not significantly more supportive than videoconferencing. These findings highlighted the importance of personalization of MR technology to enhance remote assistance. This is because personalization may increase the perceived usefulness and supportiveness of the technology and is also an important factor in user loyalty (Taghizadeh et al., 2021).

Chapter 7: Conclusion

This chapter aims to bridge the gap between theoretical framework and practical applications, ensuring the findings can practically improve the communication technologies used in remote assistance sessions. This study will summarize the key findings from our research and conclude the contributions made to the understanding of user experience within the context of user behavior and user perception with the use of different communication technologies. In addition, the limitations of this study will be discussed, and future research directions will be suggested to further investigate the implications in accordance with the communication technology used in remote assistance.

7.1 Summary of the Study

The purpose of this study was to explore the differences in user behaviors and user perceptions between the use of MR technology and videoconferencing in remote assistance sessions. The findings indicated that users exhibited varying levels of interaction and behaviors when utilizing MR technology compared with videoconferencing. We also discovered that some perspectives and experiences differ based on the role.

Of the four hypotheses examined concerning user behaviors, three were supported by the direct observation of the user interactions and quantifying them. Occurrences of uncorrected visual misalignment, unconscious body interpretations, and situational unawareness were reduced by the use of MR technology. While correctional communication was not significantly reduced, we found the reasons and possible improvements to the MR technology could be suggested to allow an improvement in this area.

Our two hypotheses regarding user perception were partially supported by the data. By analyzing the data separately, we found that different roles of users in remote assistance sessions have different perspectives on communication tools. Our findings indicated that while the MR technology is offering enhanced usefulness and supportiveness for experts, technicians did not perceive enhanced usefulness and supportiveness.

Overall, the study provided valuable insight into the impact of MR technology on user experiences in remote assistance. In addition, we also discovered that different user roles have differing perceptions which we had not anticipated in the beginning. This opens up a new area for further research into how user experience of different user roles is influenced by the communication technology in remote assistant tasks.

7.2 Contributions

The understanding gained from this research not only contributes to the academic discourse in the area of communication technology in remote assistance but also provides valuable insights into how communication and user experiences in remote assistance can be enhanced by adopting MR technologies.

7.2.1 Contributions to research

The research contributions of this study lie in the extension of our knowledge of how different communication technologies influence user behavior and perception, particularly for the experts and technicians in the context of remote assistance tasks. Currently, the studies on MR technology are typically about the equipment, the technology itself, its application, and the benefits (Fuller & Tohani, 2020; Milgram & Colquhoun, 1999; Milgram & Kishino, 1994; Oyama et al., 2021; Rebol et al., 2021); the use of MR for remote assistance (Bun, et al., 2021; Fussell et al., 2004; Mohr et al., 2020; Oyama et al., 2021); the user behavior related to the use of annotation and gestures cues (Lin et al., 2024; Obermair et al., 2020); or MR and cognitive load (Pietschmann et al., 2025; Seeliger et al., 2023; Tang et al., 2022; Xia & Wu, 2021). No studies specifically examine the behaviors of experts and technicians during the use of MR technology in remote assistance. By direct observation and testing hypotheses related to MR technology in 32 controlled laboratory experimental sessions, this study extends existing knowledge of how communication technology influences different user roles' communication behavior.

The research also applies the theory of communication grounding (Clark & Brennan, 1991) to a new context: the use of MR technology for remote assistance. Research does employ communication grounding in explaining communications in remote work and collaborations (Brennan, 1998; Cho & Rader, 2020; Gergle et al., 2012; Masson-Carro et al., 2016; Olson & Olson, 2000), however, the current literature has yet to provide explanations on the grounding cost that is evidenced by the actual behavior of experts and technicians on remote assistance tasks. This study compared the differences in grounding behavior of the two roles of users – experts and technicians – in remote assistance communication when using MR technology versus videoconferencing. The findings demonstrate how MR technology can enhance user experience by lowering the costs of communication grounding for experts and technicians.

Moreover, this study identified significant perceptual differences between experts and technicians regarding MR technology. Existing research usually collects users' perceptions of remote assistance as a homogeneous group and does not perform separate analyses for the different user types (Ahram & Falcão, 2020; Gordillo et al., 2014; Pietschmann et al., 2025; Somrak et al., 2021; Xia & Wu, 2021). Studying the user experience of the different roles in remote assistance separately is relatively rare. The findings in this research demonstrated that the users' perception of experts is more positive than that of technicians. This contradicts the implied assumption in some research that users with different roles would share similar user experiences toward the same communication technology. Though this difference was not anticipated a priori, it extends existing research as it demonstrates the need for role-specific theories and hypotheses when studying remote assistance.

Lastly, this research also contributes to the current literature on MR technology. The result from this study added the user experience findings of different communication technologies being used in remote assistance contexts. In conclusion, this research contributes significantly to our understanding of user experience by highlighting how different communication technologies influence user behavior and perception during remote interactions.

7.2.2 Contribution to practice

This research presents several practical contributions regarding the improvement and adoption of MR technology in remote assistance tasks. First, the study identifies key usability concerns when using MR technology, such as misalignment issues because of eyewear, comfort, and user habits. The fit and comfort of the MR technology can interfere with the effectiveness of the communication. It is known that personalization is important for user loyalty and has a positive impact on the acceptance of technology (Taghizadeh et al., 2021). Our research highlights the importance of tailoring communication technology devices to meet the diverse needs of users in order to create more effective and satisfying remote assistance sessions. For companies that offer MR technology, the tailoring approach can be done by delivering fitting adjustments focusing on eyeglasses, hairstyles, or wearing angles. This personalized setting can lead to improved user concentration on their tasks and increased productivity, as they no longer have to spend effort adjusting their devices or making correctional instructions. Furthermore, the personalization of the MR technology device can also provide seamless integration of technology into remote assistant tasks, giving workers a more supportive working environment and a better user experience.

Additionally, the research also confirmed that MR technology is useful in remote assistance by reducing the cost of communication grounding. This improvement is possible due to the clearer and broader view captured by MR technology devices, allowing for improved context awareness and visual alignment. Various costs of communication grounding were lowered. These benefits not only facilitate efficient collaboration but also enable workers to focus on the task at hand, eventually leading to higher productivity and job satisfaction. At the same time, our research further demonstrated that the annotation features offered by MR technology could be supportive for experts as their mental cognition load is released from conveying messages verbally. Being able to convey information more easily by reducing the need for hand gestures and verbal clarifications is essential for remote assistance. These advancements also facilitate collaborations between workers remotely and therefore for the industries adopting remote assistance, MR technologies can streamline their workflows, particularly in environments where good visual alignment and real-time collaborative responses are important, such as manufacturing, healthcare, and maintenance operations.

Lastly, the study results suggest that the experiences and needs of technicians may differ substantially from those of the experts. Technicians face more challenges when using MR technology. This implied the need for better training in MR technology for technicians to enhance their acceptance of technology and to help them better adapt to the technology and mitigate usability issues. Companies that adopt MR technology can use this insight to implement onboarding programs that target issues such as fitting and camera pointing issues that were observed during the experiments.

7.3 Limitations

Our research faced several limitations that may have influenced the results and analysis. One of the limitations was that the experiment involves collaboration between two individuals, which means different personalities, ways of giving instruction, ways of handling instructions, and use of language could act as external factors that impact the user behavior, which we collect as qualitative data for analysis. The level of gesturing among participants may vary greatly, with some participants using a lot of gestures and others using few or even none. Variation in tolerance for vision misalignment also varies greatly among participants, affecting whether they would raise it or not. These variations in individual behavior directly affected the number of counts of certain behaviors that we were measuring during the experiments. It is also worth noting that some small gestures might be missed during the coding of the videos and some misalignment might just be corrected by a simple sound made by the experts which were not being counted. These possible varieties and the errors that were made during the coding of the videos could lead to a certain degree of bias in the analysis of the results.

Participants had varying levels of experience with different instruments used during the experiment, including the Hololens, phone camera, and 3D printer, and these differences could also impact outcomes. We occasionally found that the technicians had correctly anticipated the next step, probably because that step was a procedure that they were already familiar with. This may mean that the difference between experts and technicians in terms of knowledge was not great in certain groups. It was also found that certain experts were experienced in using annotation tools and they gave particularly good instructions via the MR technology. This expertise would have contributed to a significantly better user perspective for both the expert and the technician.

Another factor to consider is the context in which the instructions were given, and the ability to understand and execute the instructions. Though this rarely happened, we do note technicians sometimes did not feel comfortable with the way experts delivered instructions. Some might not appreciate the commanding attitude, while some did not understand the instructions due to unclear communication styles. In other cases, technicians were not able to locate the tool or the menu item, even though they received very clear instructions. The irregularities might affect the user's perspective toward the communication technology.

Interrelated behavior could be another limitation in our study. There is only a relatively small variation between the behavior defined in the hypothesis of correctional communications and the behavior in the hypothesis regarding uncorrected visual misalignment, which is whether the vision is corrected by the expert. Conceptually, the two behaviors are interrelated. Correctional communications would reduce uncorrected visual misalignment. Improper alignment of the MR technology might also contribute to the high level of uncorrected visual misalignments, which are affecting the overall results in this area.

Lastly, the sample size of the study is one limitation. We had 32 samples in each group of measurement, which may not fully represent a diverse range of users. This is the reason we selected a significance level of 0.1, as less evidence is needed to reject the null hypothesis. This allows us to minimize the risk of Type II errors (also named false negatives). However, at the same time, it would increase the risk of Type I error (also named false positive). When studying user behaviors where user personality is affecting the measurements, a larger sample size might provide a more robust analysis by eliminating the effects of individual differences and reducing the impact of outliner on the statistical significance of the findings, ultimately yielding a clearer insight and strengthening the validity of the conclusions.

7.4 Future Research

Based on our study, there were several improvements and new areas that can be further explored in future studies. Future research should continue to focus on exploring the behavioral outcomes of using MR technology.

First, as mentioned in the previous chapter, this study focuses on user behavior, therefore, personality and personal habits may influence the results. A larger sample size could help to explore more into the personal effect in data collection. Further investigation with a larger sample size which explicitly examines personality would help build a more nuanced understanding of user behavior in remote assistance using different communication technologies.

Second, our post-hoc observation noted that repeated instructions occurred frequently in videoconferencing. By reviewing the recordings we have in this study, it is possible for researchers to explore more types of interaction, including but not limited to repeated instructions, that occur during remote assistance sections. By quantifying the frequency of those interactions and analyzing their effects, results could provide broader and deeper insight into user behavior and communication effectiveness when using MR technology.

Future research should also take the personalization of technology into account. In this study, although the MR technology offers more advanced features, technicians do not perceive it as more supportive in remote assistant tasks than videoconferencing. A considerable number of vision alignment issues with MR technology were found due to the physical interference caused by the eyeglasses or hairstyles, highlighting the need for better design of the integration of corrective eyewear and MR technology. Future research could be done with MR technology, which incorporates adaptive fitting mechanisms, addressing the physical challenges of eyewear or hairstyles. With the personalization of MR technology, it is expected that technicians will benefit from improved communication and user experience, leading to a better user perception of MR technology.

In addition, MR technology could support more than just annotation. Software and interface enhancement could be done in terms of video exchange. In the current study, video is captured by the technician and displayed to the expert. Future research could integrate the view of the technician with video capturing the expert. This dual video exchange approach would enable experts to show the steps in action, allowing technicians to follow along in real-time. This real-time video exchange would provide immediate feedback and guidance, enhancing the collaborative process between technicians and experts. This would save a lot of effort in explanation and understanding, reducing the cost of grounding in communication, and eventually leading to more efficient communication and better user experience.

Altogether, we can conclude that the integration of MR technology in remote assistance has not only demonstrated improved user experiences for the experts and improved communication between experts and technicians but also has the potential for further improvements. By addressing the identified challenges and exploring the suggested areas for future research, researchers can contribute a deeper understanding of the behavior and potential benefit of MR technology for remote assistance tasks.

Bibliography

Agyeiwaah, E., Badu Baiden, F., Gamor, E., & Hsu, F.-C. (2022). Determining the attributes that influence students' online learning satisfaction during COVID-19 pandemic. *Journal of Hospitality, Leisure, Sport & Tourism Education*, *30*, 100364. https://doi.org/10.1016/j.jhlste.2021.100364

Ahram, T., & Falcão, C. (Eds.). (2020). *Advances in Usability, User Experience, Wearable and Assistive Technology: Proceedings of the AHFE 2020 Virtual Conferences on Usability and User Experience, Human Factors and Assistive Technology, Human Factors and Wearable Technologies, and Virtual Environments and Game Design, July 16-20, 2020, USA* (Vol. 1217). Springer International Publishing. https://doi.org/10.1007/978-3-030-51828-8

Alem, L., Tecchia, F., & Huang, W. (2011). *Remote Tele-assistance System for Maintenance Operators in Mines*. https://ro.uow.edu.au/articles/conference_contribution/Remote_Tele-assistance_System_for_Maintenance_Operators_in_Mines/27685254

Arnheim, R., & McNeill, D. (1994). Hand and Mind: What Gestures Reveal about Thought. *Leonardo*, *27*(4), 358. https://doi.org/10.2307/1576015

Attaran, M., Attaran, S., & Kirkland, D. (2019). The Need for Digital Workplace: Increasing Workforce Productivity in the Information Age. *International Journal of Enterprise Information Systems*, *15*(1), 1–23. https://doi.org/10.4018/IJEIS.2019010101

Bavelas, J., Gerwing, J., Allison, M., & Sutton, C. (2011). Chapter 4. Dyadic evidence for grounding with abstract deictic gestures. In *Integrating Gestures*. John Benjamins.

https://www.jbe-platform.com/content/books/9789027287205-gs.4.05bav

Billinghurst, M., & Kato, H. (2002). Collaborative augmented reality. *Communications of the ACM*, *45*(7), 64–70. https://doi.org/10.1145/514236.514265

Blattgerste, J., Strenge, B., Renner, P., Pfeiffer, T., & Essig, K. (2017). Comparing Conventional and Augmented Reality Instructions for Manual Assembly Tasks. *Proceedings of the 10th International Conference on PErvasive Technologies Related to Assistive Environments*, 75–82. https://doi.org/10.1145/3056540.3056547

Bly, S. A., Harrison, S. R., & Irwin, S. (1993). Media spaces: Bringing people together in a video, audio, and computing environment. *Communications of the ACM*, *36*(1), 28–46. https://doi.org/10.1145/151233.151235

Brennan, S. E. (1998). The Grounding Problem in Conversations With and Through Computers. In S. R. Fussell & R. J. Kreuz (Eds.), *Social and Cognitive Approaches to Interpersonal Communication* (pp. 201–225). Lawrence Erlbaum.

Brennan, S. E., & Lockridge, C. B. (2006). Computer-Mediated Communication: Cognitive Science Approach. In *Encyclopedia of Language & Linguistics* (pp. 775–780). Elsevier. https://doi.org/10.1016/B0-08-044854-2/00861-0

Brooke, J. (1995). SUS: A quick and dirty usability scale. *Usability Eval. Ind.*, *189*.

Bun, P., Grajewski, D., & Gorski, F. (2021). Using augmented reality devices for remote support in manufacturing: A case study and analysis. *Advances in Production Engineering & Management*, *16*(4), 418–430. https://doi.org/10.14743/apem2021.4.410

Canelón, R., Carrasco, C., & Rivera, F. (2024). Design of a remote assistance model for truck maintenance in the mining industry. *Journal of Quality in Maintenance Engineering*, *30*(1), 175–201. https://doi.org/10.1108/JQME-02-2023-0024

Chandler, P., & Sweller, J. (1991). Cognitive Load Theory and the Format of Instruction. *Cognition and Instruction*, *8*(4), 293–332. https://doi.org/10.1207/s1532690xci0804_2

Chatterjee, S., Chaudhuri, R., & Vrontis, D. (2022). Does remote work flexibility enhance organization performance? Moderating role of organization policy and top management support. *Journal of Business Research*, *139*, 1501–1512. https://doi.org/10.1016/j.jbusres.2021.10.069

Chen, M., Tang, Q., Xu, S., Leng, P., & Pan, Z. (2020). Design and Evaluation of an Augmented Reality-Based Exergame System to Reduce Fall Risk in the Elderly. *International Journal of Environmental Research and Public Health*, *17*(19), 7208. https://doi.org/10.3390/ijerph17197208

Cho, J., & Rader, E. (2020). The Role of Conversational Grounding in Supporting Symbiosis Between People and Digital Assistants. *Proceedings of the ACM on Human-Computer Interaction*, *4*(CSCW1), 1–28. https://doi.org/10.1145/3392838

Clark, H. H., & Brennan, S. E. (1991). Grounding in communication. In L. B. Resnick, J. M. Levine, & S. D. Teasley (Eds.), *Perspectives on socially shared cognition.* (pp. 127–149). American Psychological Association. https://doi.org/10.1037/10096-006

Clark, H. H., & Krych, M. A. (2004). Speaking while monitoring addressees for understanding. *Journal of Memory and Language*, *50*(1), 62–81. https://doi.org/10.1016/j.jml.2003.08.004

Clark, H. H., & Schaefer, E. F. (1989). Contributing to Discourse. *Cognitive Science*, *13*(2), 259–294. https://doi.org/10.1207/s15516709cog1302_7

Clark, H. H., & Wilkes-Gibbs, D. (1986). Referring as a collaborative process. *Cognition*, *22*(1), 1–39. https://doi.org/10.1016/0010-0277(86)90010-7

Cooper, J. M., & Strayer, D. L. (2025). Multitasking Induced Contextual Blindness. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *67*(3), 225–245. https://doi.org/10.1177/00187208241274040

Da Silva, C. R. C., Garcia, A. C. B., & Da Rosa, J. M. C. (2011). SLMeetingRoom: A model of environment to remote support meetings, oriented tasks with small groups for Second Life. *Proceedings of the 2011 15th International Conference on Computer Supported Cooperative Work in Design (CSCWD)*, 524–531. https://doi.org/10.1109/CSCWD.2011.5960122

Daft, R. L., & Lengel, R. H. (1986). Organizational Information Requirements, Media Richness and Structural Design. *Management Science*, *32*(5), 554–571. https://doi.org/10.1287/mnsc.32.5.554

Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly*, *13*(3), 319. https://doi.org/10.2307/249008

Domova, V., Vartiainen, E., & Englund, M. (2014). Designing a Remote Video Collaboration System for Industrial Settings. *Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces*, 229–238. https://doi.org/10.1145/2669485.2669517

Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and Limitations of Immersive Participatory Augmented Reality Simulations for Teaching and Learning. *Journal of Science Education and Technology*, *18*(1), 7–22. https://doi.org/10.1007/s10956-008-9119-1

Endsley, M. R. (1995). Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *37*(1), 32–64.

https://doi.org/10.1518/001872095779049543

Fakourfar, O., Ta, K., Tang, R., Bateman, S., & Tang, A. (2016). Stabilized Annotations for Mobile Remote Assistance. *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 1548–1560. https://doi.org/10.1145/2858036.2858171

Fidalgo, C. G., Yan, Y., Cho, H., Sousa, M., Lindlbauer, D., & Jorge, J. (2023). A Survey on Remote Assistance and Training in Mixed Reality Environments. *IEEE Transactions on Visualization and Computer Graphics*, *29*(5), 2291–2303. https://doi.org/10.1109/TVCG.2023.3247081

Fuller, H., & Tohani, M. (2020). *Smart Innovators: Augmented reality solutions for remote assistance*. Verdantix. https://www.verdantix.com/report/smart-innovators-augmented-reality-solutions-for-remote-assistance

Fussell, S. R., Setlock, L. D., Yang, J., Ou, J., Mauer, E., & Kramer, A. D. I. (2004). Gestures Over Video Streams to Support Remote Collaboration on Physical Tasks. *Human–Computer Interaction*, *19*(3), 273–309. https://doi.org/10.1207/s15327051hci1903_3

Gergle, D., Kraut, R. E., & and, S. R. F. (2012). Using Visual Information for Grounding and Awareness in Collaborative Tasks. *Human–Computer Interaction*, *28*(1), 1–39. https://doi.org/10.1080/07370024.2012.678246

Gifford, J. (2022). Remote working: Unprecedented increase and a developing research agenda. *Human Resource Development International*, *25*(2), 105–113. https://doi.org/10.1080/13678868.2022.2049108

Gordillo, A., Barra, E., Aguirre, S., & Quemada, J. (2014). The usefulness of usability and user experience evaluation methods on an e-Learning platform development from a developer's perspective: A case study. *2014 IEEE Frontiers in Education Conference*

(FIE) Proceedings, 1–8. https://doi.org/10.1109/FIE.2014.7044340

Greenstein, S. (2021). Remote Work. *IEEE Micro*, *41*(3), 110–112. https://doi.org/10.1109/MM.2021.3073433

Heath, C., & Luff, P. (1991). Disembodied conduct: Communication through video in a multi-media office environment. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems Reaching through Technology - CHI '91*, 99–103. https://doi.org/10.1145/108844.108859

Iksan, E. I., & Mardhia, M. M. (2023). The Role of EEG Signals: SVM Classification of Cognitive Load as a Support for UX Evaluation. *Journal of Intelligent Computing & Health Informatics*, *4*(1), 20. https://doi.org/10.26714/jichi.v4i1.11198

Karis, D., Wildman, D., & Mané, A. (2016). Improving Remote Collaboration With Video Conferencing and Video Portals. *Human–Computer Interaction*, *31*(1), 1–58. https://doi.org/10.1080/07370024.2014.921506

Krauss, R. M., & Weinheimer, S. (1966). Concurrent feedback, confirmation, and the encoding of referents in verbal communication. *Journal of Personality and Social Psychology*, *4*(3), 343–346. https://doi.org/10.1037/h0023705

Kraut, R. E., Fussell, S. R., & Siegel, J. (2003). Visual Information as a Conversational Resource in Collaborative Physical Tasks. *Human–Computer Interaction*, *18*(1–2), 13–49. https://doi.org/10.1207/S15327051HCI1812_2

Kraut, R. E., Miller, M. D., & Siegel, J. (1996). Collaboration in performance of physical tasks: Effects on outcomes and communication. *Proceedings of the 1996 ACM Conference on Computer Supported Cooperative Work - CSCW '96*, 57–66. https://doi.org/10.1145/240080.240190

Kuhar, M., & Merčun, T. (2022). Exploring user experience in digital libraries through questionnaire and eye-tracking data. *Library & Information Science Research*, *44*(3), 101175. https://doi.org/10.1016/j.lisr.2022.101175

Kumar, C. B., Potnis, A., & Gupta, S. (2015). Video conferencing system for distance education. *2015 IEEE UP Section Conference on Electrical Computer and Electronics (UPCON)*, 1–6. https://doi.org/10.1109/UPCON.2015.7456682

Kumar, N., Kumar, J., & Kumar, J. (2022). A Comparative Study of Prototyping Methods for HCI Design Using Cognitive Load-Based Measures. In M. Kurosu, S. Yamamoto, H. Mori, M. M. Soares, E. Rosenzweig, A. Marcus, P.-L. P. Rau, D. Harris, & W.-C. Li (Eds.), *HCI International 2022—Late Breaking Papers. Design, User Experience and Interaction* (Vol. 13516, pp. 43–58). Springer International Publishing. https://doi.org/10.1007/978-3-031-17615-9_4

Lanir, J., Stone, R., Cohen, B., & Gurevich, P. (2013). Ownership and control of point of view in remote assistance. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2243–2252. https://doi.org/10.1145/2470654.2481309

Lin, H., Wen, L., Geng, H., Li, J., Wang, H., & Li, H. (2024). Research on Remote Annotation and Supervision for Mixed Reality. *2024 3rd Asian Conference on Frontiers of Power and Energy (ACFPE)*, 364–368. https://doi.org/10.1109/ACFPE63443.2024.10800869

Luff, P., Heath, C., Kuzuoka, H., Hindmarsh, J., Yamazaki, K., & Oyama, S. (2003). Fractured Ecologies: Creating Environments for Collaboration. *Human–Computer Interaction*, *18*(1–2), 51–84. https://doi.org/10.1207/S15327051HCI1812_3

Marion, T. J., & Fixson, S. K. (2021). The Transformation of the Innovation Process: How Digital Tools are Changing Work, Collaboration, and Organizations in New Product

Development*. *Journal of Product Innovation Management*, *38*(1), 192–215. https://doi.org/10.1111/jpim.12547

Masson-Carro, I., Goudbeek, M., & Krahmer, E. (2016). Imposing Cognitive Constraints on Reference Production: The Interplay Between Speech and Gesture During Grounding. *Topics in Cognitive Science*, *8*(4), 819–836. https://doi.org/10.1111/tops.12217

Mehler-Bicher, A., Steiger, L., & Weitzel, D. (2023). Mixed Reality Applications in Business Contexts. In J. Rosen (Ed.), *Holography—Recent Advances and Applications*. IntechOpen. https://doi.org/10.5772/intechopen.106582

Meiners, A.-L., Schrepp, M., Hinderks, A., & Thomaschewski, J. (2024). A Benchmark for the UEQ+ Framework: Construction of a Simple Tool to Quickly Interpret UEQ+ KPIs. *International Journal of Interactive Multimedia and Artificial Intelligence*, *9*(1), 104. https://doi.org/10.9781/ijimai.2023.05.003

Meis, M., Pirani, M., Euan, C., Castruccio, S., Simmons, S., Stroud, J. R., Blangiardo, M., Wikle, C. K., Wheeler, M., Naumova, E., Bravo, L., Miller, C., & Gel, Y. (2024). Catalysing virtual collaboration: The experience of the remote TIES working groups. *Environmetrics*, *35*(6), e2855. https://doi.org/10.1002/env.2855

Milgram, P., & Colquhoun, H. (1999). A Taxonomy of Real and Virtual World Display Integration. In Y. Ohta & H. Tamura (Eds.), *Mixed Reality* (pp. 5–30). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-87512-0_1

Milgram, P., & Kishino, F. (1994). A Taxonomy of Mixed Reality Visual Displays. *IEICE Trans. Information Systems*, *E77-D, no. 12*, 1321–1329.

Mohr, P., Mori, S., Langlotz, T., Thomas, B. H., Schmalstieg, D., & Kalkofen, D. (2020). Mixed Reality Light Fields for Interactive Remote Assistance. *Proceedings of the 2020 CHI*

Conference on Human Factors in Computing Systems, 1–12. https://doi.org/10.1145/3313831.3376289

Narayanamma, K. L., Nagpal, A., Adnan, K., Mahenderreddy, M., & Raju, K. B. (2024). Metaverse-Based Virtual Workspace to Support Team Collaboration in the Laboratory: In R. Bansal & R. Lampou (Eds.), *Advances in Human Resources Management and Organizational Development* (pp. 99–116). IGI Global. https://doi.org/10.4018/979-8-3693-6839-8.ch006

Naumov, I., Sinakin, M., Sinakina, O., & Voronin, V. V. (2021). Using augmented reality devices for remote maintenance and repair of industrial equipment as new challenges in the COVID-19 pandemic. In C. Peroz & B. C. Kress (Eds.), *Digital Optical Technologies 2021* (p. 4). SPIE. https://doi.org/10.1117/12.2593444

Nguyen, T., Brown, E., Chauhan, K., Lee, B., & Erensen, J. (2024). *Emerging Tech: Revenue Opportunity Projection for AR and VR Head-Mounted Displays*. Gartner Research. https://www.gartner.com/en/documents/5179263

Niedermayr, D., Wolfartsberger, J., Borac, M., Brandl, R., Huber, M., & Josipovic, P. (2022). Analyzing the Potential of Remote Collaboration in Industrial Mixed and Virtual Reality Environments. *2022 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*, 66–73. https://doi.org/10.1109/ISMAR-Adjunct57072.2022.00023

Obermair, F., Althaler, J., Seiler, U., Zeilinger, P., Lechner, A., Pfaffeneder, L., Richter, M., & Wolfartsberger, J. (2020b). Maintenance with Augmented Reality Remote Support in Comparison to Paper-Based Instructions: Experiment and Analysis. *2020 IEEE 7th International Conference on Industrial Engineering and Applications (ICIEA)*, 942–947.

https://doi.org/10.1109/ICIEA49774.2020.9102078

Olson, G. M., & Olson, J. S. (2000). Distance Matters. *Human–Computer Interaction*, *15*(2–3), 139–178. https://doi.org/10.1207/S15327051HCI1523_4

Oyama, E., Tokoi, K., Suzuki, R., Nakamura, S., Shiroma, N., Watanabe, N., Agah, A., Okada, H., & Omori, T. (2021). Augmented reality and mixed reality behavior navigation system for telexistence remote assistance. *Advanced Robotics*, *35*(20), 1223–1241. https://doi.org/10.1080/01691864.2021.1976670

Paas, F. G. W. C., & Van Merriënboer, J. J. G. (1993). The Efficiency of Instructional Conditions: An Approach to Combine Mental Effort and Performance Measures. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *35*(4), 737–743. https://doi.org/10.1177/001872089303500412

Pietschmann, L., Schimpf, M., Chen, Z.-T., Pfister, H., & Bohné, T. (2025). *Enhancing User Performance and Human Factors through Visual Guidance in AR Assembly Tasks*. https://doi.org/10.48550/ARXIV.2503.05649

Popovici, V., & Popovici, A.-L. (2020). Remote Work Revolution: Current Opportunities and Challenges for Organizations. *Ovidius University Annals, Economic Sciences Series*, *0*(1), 468–472.

Rebol, M., Hood, C., Ranniger, C., Rutenberg, A., Sikka, N., Horan, E. M., Gutl, C., & Pietroszek, K. (2021). Remote Assistance with Mixed Reality for Procedural Tasks. *2021 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*, 653–654. https://doi.org/10.1109/VRW52623.2021.00209

Richardson, T., MacAllister, A., Holub, J., Thompson, F., Radkowski, R., Winer, E., Gilbert, S., Davies, P., & Terry, S. (2014). Fusing Self-Reported and Sensor Data from Mixed-

Reality Training. *The Interservice/Industry Training, Simulation & Education Conference (I/ITSEC)*. https://doi.org/20.500.12876/44354

Roque, A., & Traum, D. (2008). Degrees of Grounding Based on Evidence of Understanding. In D. Schlangen & B. A. Hockey (Eds.), *Proceedings of the 9th SIGdial Workshop on Discourse and Dialogue* (pp. 54–63). Association for Computational Linguistics. https://aclanthology.org/W08-0107/

Schmalstieg, D., & Höllerer, T. (2016). *Augmented reality: Principles and practice*. Addison-Wesley.

Schmidt, K. (2002). The Problem with `Awareness': Introductory Remarks on `Awareness in CSCW'. *Computer Supported Cooperative Work (CSCW)*, *11*(3–4), 285–298. https://doi.org/10.1023/A:1021272909573

Schrepp, M., Hinderks, A., & Thomaschewski, J. (2017a). Construction of a Benchmark for the User Experience Questionnaire (UEQ). *International Journal of Interactive Multimedia and Artificial Intelligence*, *4*(4), 40. https://doi.org/10.9781/ijimai.2017.445

Schrepp, M., Hinderks, A., & Thomaschewski, J. (2017b). Design and Evaluation of a Short Version of the User Experience Questionnaire (UEQ-S). *International Journal of Interactive Multimedia and Artificial Intelligence*, *4*(6), 103. https://doi.org/10.9781/ijimai.2017.09.001

Schrock, A. (2015). Communicative Affordances of Mobile Media: Portability, Availability, Locatability, and Multimediality. *International Journal of Communication*, *9*, 1229–1246.

Seeliger, A., Cheng, L., & Netland, T. (2023). Augmented reality for industrial quality inspection: An experiment assessing task performance and human factors. *Computers in*

Industry, *151*, 103985. https://doi.org/10.1016/j.compind.2023.103985

Skulmowski, A., & Rey, G. D. (2017). Measuring Cognitive Load in Embodied Learning Settings. *Frontiers in Psychology*, *8*, 1191. https://doi.org/10.3389/fpsyg.2017.01191

Somrak, A., Pogačnik, M., & Guna, J. (2021). Suitability and Comparison of Questionnaires Assessing Virtual Reality-Induced Symptoms and Effects and User Experience in Virtual Environments. *Sensors*, *21*(4), 1185. https://doi.org/10.3390/s21041185

Statista. (2025, March). *Number of smartphone users worldwide 2014-2029*. https://www.statista.com/forecasts/1143723/smartphone-users-in-the-world

Sweller, J. (1988). Cognitive Load During Problem Solving: Effects on Learning. *Cognitive Science*, *12*(2), 257–285. https://doi.org/10.1207/s15516709cog1202_4

Taghizadeh, H., Panahi, K., & Iranzadeh, S. (2021). The Impact of Personalization on Customers' Loyalty and the Intention to Use E-banking Services. *International Economics Studies*, *51*(2). https://doi.org/10.22108/ies.2022.132161.1125

Tang, Y. M., Chau, K. Y., Kwok, A. P. K., Zhu, T., & Ma, X. (2022). A systematic review of immersive technology applications for medical practice and education—Trends, application areas, recipients, teaching contents, evaluation methods, and performance. *Educational Research Review*, *35*, 100429. https://doi.org/10.1016/j.edurev.2021.100429

Teo, T., Lee, G. A., Billinghurst, M., & Adcock, M. (2018). Hand gestures and visual annotation in live 360 panorama-based mixed reality remote collaboration. *Proceedings of the 30th Australian Conference on Computer-Human Interaction*, 406–410. https://doi.org/10.1145/3292147.3292200

Venkatesh, V., & Davis, F. D. (2000). A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies. *Management Science*, *46*(2), 186–204.

https://doi.org/10.1287/mnsc.46.2.186.11926

Waizenegger, L., McKenna, B., Cai, W., & Bendz, T. (2020). An affordance perspective of team collaboration and enforced working from home during COVID-19. *European Journal of Information Systems*, *29*(4), 429–442. https://doi.org/10.1080/0960085X.2020.1800417

Wolfartsberger, J., Zenisek, J., & Wild, N. (2020). Data-Driven Maintenance: Combining Predictive Maintenance and Mixed Reality-supported Remote Assistance. *Procedia Manufacturing*, *45*, 307–312. https://doi.org/10.1016/j.promfg.2020.04.022

Worlikar, H., Coleman, S., Kelly, J., O'Connor, S., Murray, A., McVeigh, T., Doran, J., McCabe, I., & O'Keeffe, D. (2023). Mixed Reality Platforms in Telehealth Delivery: Scoping Review. *JMIR Biomedical Engineering*, *8*, e42709. https://doi.org/10.2196/42709

Xia, X., & Wu, W. (2021). User Experience of Virtual Reality Interfaces Based on Cognitive Load. In T. Z. Ahram & C. S. Falcão (Eds.), *Advances in Usability, User Experience, Wearable and Assistive Technology* (Vol. 275, pp. 340–347). Springer International Publishing. https://doi.org/10.1007/978-3-030-80091-8_40

Zhang, H., Cui, Y., Shan, H., Qu, Z., Zhang, W., Tu, L., & Wang, Y. (2020). Hotspots and Trends of Virtual Reality, Augmented Reality and Mixed Reality in Education Field. *2020 6th International Conference of the Immersive Learning Research Network (iLRN)*, 215–219. https://doi.org/10.23919/iLRN47897.2020.9155170

Zhang, J., Yu, N., Wang, B., & Lv, X. (2022). Trends in the Use of Augmented Reality, Virtual Reality, and Mixed Reality in Surgical Research: A Global Bibliometric and Visualized Analysis. *Indian Journal of Surgery*, *84*(S1), 52–69. https://doi.org/10.1007/s12262-021-03243-w

Zhou, W. (2023). Application Research of Cognitive Load Theory in User Experience DesignTake the User Experience Design of Takeaway Deliverymen in Unmanned Distribution Business as an Example. *Lecture Notes in Education Psychology and Public Media*, *3*(1), 722–732. https://doi.org/10.54254/2753-7048/3/2022299

Appendix

Appendix A. Research Ethics Board Project Modification Form and Approval

i.) Ethics approval of research project:

HEC MONTRĒAL

Comité d'éthique de la recherche

May 27, 2024

To the attention of: Edward Opoku-Mensah

Re: Ethics approval of your research project

Project No.: 2025-5960
Title of research project: Communication through Technology for Remote Support Tasks

Funding source : R2402 - CRSH
Title of the grant : Canada Research Chair in Digital Communication and Multitasking

Dear Edward Opoku-Mensah,

Your research project has been evaluated in accordance with ethical conduct for research involving human subjects by the Research Ethics Board (REB) of HEC Montréal.

A Certificate of Ethics Approval attesting that your research complies with HEC Montréal's *Policy on Ethical Conduct for Research Involving Humans* has been issued, effective May 27, 2024. This certificate is **valid until May 01, 2025.**

Please note that you are required to renew your ethics approval before your certificate expires using Form *F7 – Annual Renewal*. You will receive an automatic reminder by email a few weeks before your certificate expires.

If any changes are made to your project before the certificate expires, you must complete *F8 – Project Modification* and obtain REB approval before implementing those changes. If your project is completed before the certificate expires, you must complete Form *F9 – Termination of Project* or *F9a – Termination of Student Project*, as applicable.

Under the *Policy on Ethical Conduct for Research Involving Humans*, researchers are responsible for ensuring that their research projects maintain ethics approval for the entire duration of the research work, and for informing the REB of its completion. In addition, any significant changes to the project must be submitted to the REB for approval before they are implemented.

You may now begin the data collection for which you obtained this certificate.

We wish you every success in your research.

REB of HEC Montréal

ii.) Signed Form F:

HEC MONTRÉAL

Form F
CONFIDENTIALITY AGREEMENT

Title: Communication through technology for remote support tasks

Identification of the member(s) of the research team:

Principal investigator: Edward Opoku-Mensah

Master's or doctoral thesis supervisor: Ann-Frances Cameron

Terms of the commitment:

We, the undersigned, who are responsible for the collection of data in relation to the research project mentioned above, formally agree to:

A. Ensure the protection, security and confidentiality of the data gathered from participants as well as any data concerning human subjects consulted in the databases;

B. Take the necessary steps to protect the identity of participants and of human subjects associated to consulted data and to ensure against their inadvertent identification during the process of gathering data.

C. Avoid the divulgation of information obtained from participants or Identifiable Information obtained from consulted data concerning human subjects without the authorization of participants or the without the approbation of HEC Montreal's Research ethics committee or unless required by law;

Refrain from using the data gathered or consulted as part of this project for purposes other than those approved by HEC Montréal's Research Ethics Board.

Researcher's first and last name	Signature	Date (dd/mm/yyyy)
Yu Shiu Ying	[signature]	26/09/2024

iii.) Project Modification Approval:

HEC MONTRÉAL

Comité d'éthique de la recherche

October 08, 2024

To the attention of: Edward Opoku-Mensah

Co-researchers: Scott Bateman

Project No.: 2025-5960

Project title: Communication through Technology for Remote Support Tasks

Funding source : SSHRC (R2402)

Dear Edward Opoku-Mensah,

Further to the evaluation of your Form F8 – Project Modification, the Research Ethics Board (REB) of HEC Montréal wishes to inform you of its decision:

The changes have been noted in the file. The current certificate will remain valid until the next renewal.

The account (CCS) is now associated with this approbation.

Project approval: May 27, 2024

Certification renwal due date : May 01, 2025

Thank you.

REB of HEC Montréal

NAGANO www.semiweb.ca Form approval
Comité d'éthique de la recherche - HEC Montréal 1 / 1

Appendix B. Test Execution Protocol

This document outlines the procedures to be followed to conduct the experiments.

1. Pre-Test Setup

- Counterbalance measurement:
  - Number of task sequences: 2
  - Number of technologies: 2
- Prepare iPad for pre-task / post-task questionnaires.
  - 4 Qualtrics sequences - depends on the sequence × technology condition.
- Set up HoloLens device.
- Set up the mobile phone for Microsoft Teams meeting.
- Set up TV screens for:
  - Video conferencing
  - MR technology streaming in the expert room
- Set up the secondary screen for displaying legend picture reference.
- Set up the laptop for expert instructions.
- Set up the 3D printer
- Set up the recording software
- Prepare and shuffle role labels (for counterbalancing conditions).

2. Participant Welcome & Introduction

- Welcome the participant.
- Provide a brief explanation of the experiment.
- Counterbalance measurement:
  - Role: Expert vs Technician
- Distribute and collect the consent form.

3. Mental Rotation Test

4. Pre-Task Questionnaire

5. Task Execution – Technology 1

a. Training Phase

- Explain the context of the task with Technology 1.
- Mute for technician.
- Provide training instructions to the expert.
- Unmute for technician.
- Start recording
- Conduct Training 1 with the participants.
- Complete the post-training questionnaire.

b. Task Phase

- Mute for technician.
- Explain Task 1 to the expert.
- Unmute for technician.
- Conduct Task 1 with the participants.
- Complete the post-task questionnaire.

6. Transition to Technology 2

- Set up the second technology.
- Reset the printer and accessories for the next section.

7. Task Execution – Technology 2

a. Training Phase

- Explain the context of the task with Technology 2.
- Mute for technician.
- Provide training instructions to the expert.
- Unmute for technician.
- Conduct Training 2 with the participants.
- Complete the post-training questionnaire.

b. Task Phase

- Mute for technician.
- Explain Task 2 to the expert.
- Unmute for technician.
- Conduct Task 2 with the participants.
- Stop recording.
- Complete the post-task questionnaire.

8. Closing Procedures

- Check the questionnaire submission status.
- Thank the participant.
- Complete and collect the compensation form.
- Conduct a short informal debrief, to remind them not to disclose any details of the study to others.
- Reset printer and accessories.

Appendix C. Script Protocol

Credit: Principal researcher Edward Opoku-Mensah, PhD Student

This document outlines the script read to the participants as a protocol to make sure all participants receive the same information.

Participant Welcome

- Thank you for participating in this experiment. I am Edward, a PhD student (and with me is Samuel, a Masters Student) working with Prof. Ann-Frances Cameron. The study is conducted by both HEC Montreal (with Professor Cameron), and the University of New Brunswick (with Professor Scott Bateman)
- What I am reading is a standard protocol to make sure all participants receive the same information.
- Before we start, please ensure all belongings, including the phone, are safely locked outside the study room (with the phone on silence).
- Please feel free to use the washroom before we begin.

About the study:

- The study is about communication with remote assistance.
- The two rooms represent two different locations. They could be 2 different countries or different cities.
- Participant in room 1 will be playing the role of the technician, who requires assistance from the participant in room 2, the expert, in figuring out how to set up a new technology, the 3D printer.
- There will be no surprises. Everything will be provided for you to play your roles.
- For this experiment, we will have 2 primary tasks. Each task we will have 1 training with the corresponding technology. Before that, we'll have an MRT test and pretest questionnaire. But for now, I will give you the consent form then we start.
- Anytime you're done, Just raise your hands once and wait. Not to put pressure on the other participant who hasn't finished. Any questions?

- If you have any questions after the experiment, we have our details here for the Professors in charge.

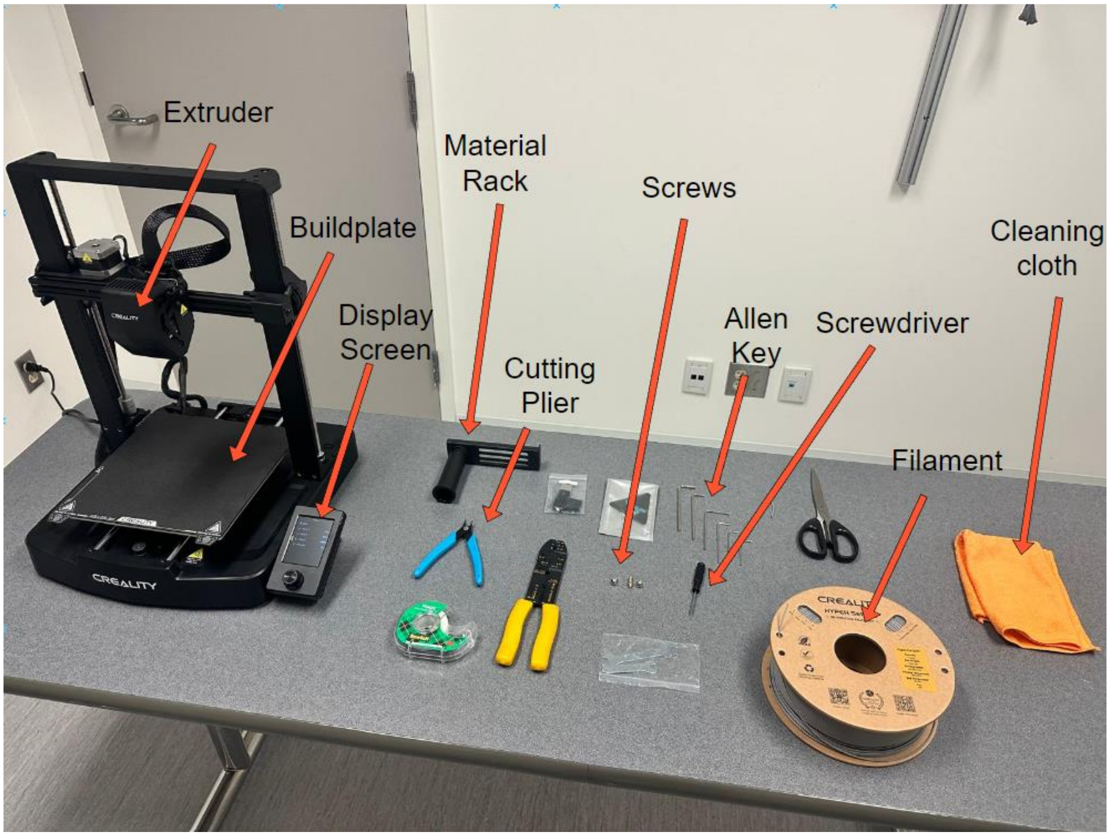
The consent form

- This is an information and consent form which describes our experiment and explains all ethical procedures related to data collection. Please take your time to read the consent form and let me know if you have any questions. Let me know when you are done.

Appendix D. Participant Guide for Expert

Credit: Principal researcher Edward Opoku-Mensah, PhD Student

i.) Expert guide for training:



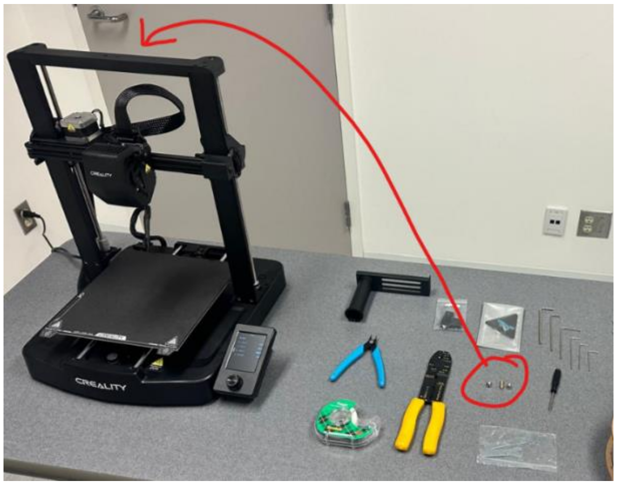
All Components and names

TRAINING TASK

- To begin, you need to take the **Material Rack.**

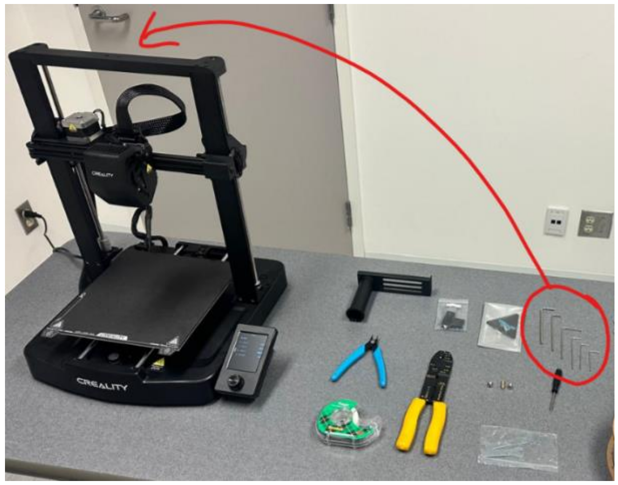
Provide similar annotation to teammate if required

- You also need to take the two identical screws (Hexagon Socket Button Head Screws) to hold it into position.



Provide similar annotation to teammate if required

- Finally, you will need a suitable Allen key, that will be used to screw the material rack tightly into position (It is the second biggest key).



Provide similar annotation to teammate if required

- Place the material rack to stand on the top of the 3D printer, with the pointed side facing the front of the printer.
- Insert the two screws.
- And use the **Allen key** to tighten it into position.

Provide similar annotation to teammate if required

ii.) Expert guide for high complexity task:

Kind reminder: Your partner is using the HoloLens, and you can use the 3D annotation feature to point out or highlight specific areas or objects while providing assistance.

THE TASK (FILAMENT SWAP)

One of our students wants to use a filament for printing, let's set up the filament for the student.

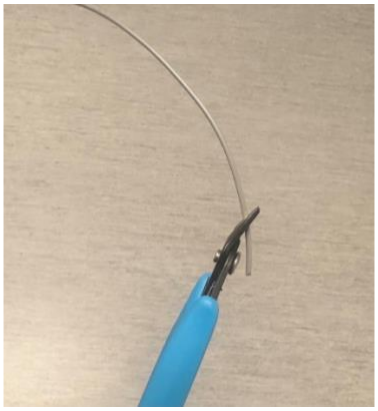
- Now take the **filament** and insert it in the **Material Assembly Rack** on top of the printer.
    - And make sure the yellow label on the filament is facing the front side of the printer

Provide similar annotation to teammate if required

- You need you to check the **Display Screen**.

Provide similar annotation to teammate if required

- Rotate the button to highlight the "**Prepare**" options displayed, and push the button down to select.
- Rotate the display screen button to choose "**Extrude**".
- Wait for a few seconds when you see the **Extruder** moving.
- Cut the tip of the filament with a **Cutting plier** at 45 degrees, and throw the cut piece away.

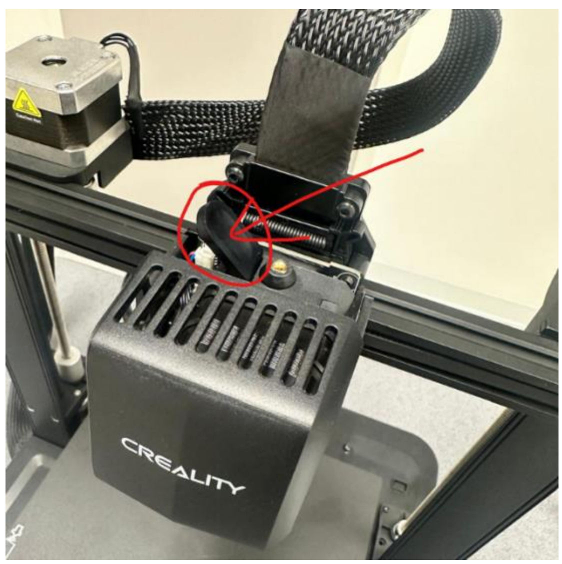


Provide similar annotation to teammate if required

- Now let's focus on the Extruder

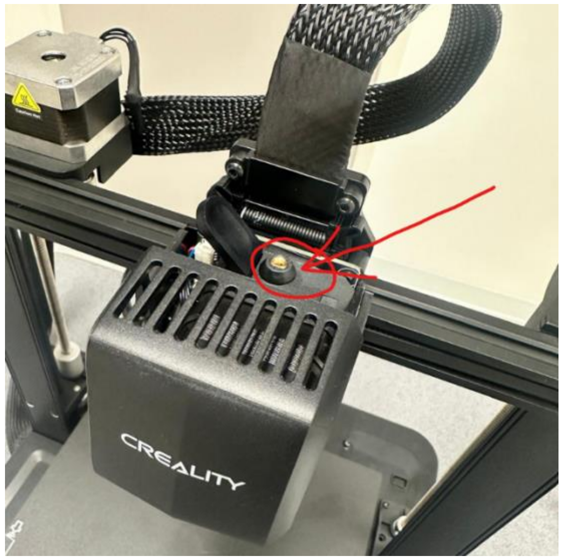
Provide similar annotation to teammate if required

- At the top of the **extruder** push the **extruder lock** downwards and hold it down to allow the filament in.



Provide similar annotation to teammate if required

  - Insert the tip of the **filament** into the **extruder hole**.

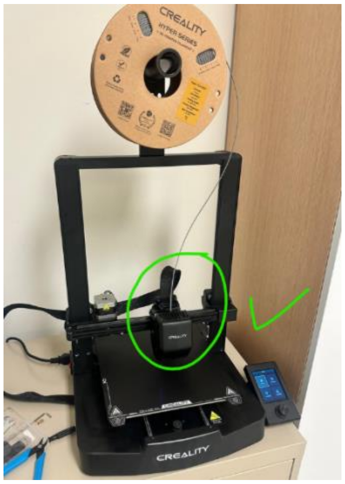


Provide similar annotation to teammate if required

- Wait when you see the **Extruder moving** wait for it to stop moving.
- Anytime you see the **CONFIRM** displayed on the screen, click on it **ONLY ONCES AND WAIT** a few seconds before moving on.
- Now **wait** for a while. After the **Display screen** is done matching some progress such as 248/248 or 65/65, or when the numbers stop moving, you can continue the next step.

Provide similar annotation to teammate if required

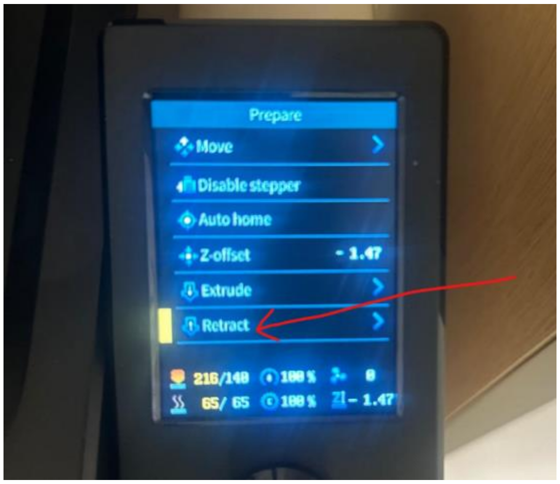
- If you see the **CONFIRM** displayed on the screen, click on it **ONLY ONCES AND WAIT** a few seconds before proceeding.
- Now Push the filament downwards until it hits the bottom of the extruder. Then push down the display screen button to continue



Provide similar annotation to teammate if required

Great, now that we have setup the filament successfully. We are going to remove it, for any other student to use the printer with their own filament.

- From the Display screen, choose **Retract.**



Provide similar annotation to teammate if required

- **IF** the **Homing** page is displayed, wait for it to finish, to be able to proceed.
- Now when you see the **Retracting** page, wait again for the readings to match the progress levels such as 248/248 or 65/65, **or** when the numbers stop moving to continue.
- The extruder will now slowly push the filament out. Once the **pull-out page** is displayed, push the **extruder lock** downwards and remove the filament from the extruder.

Provide similar annotation to teammate if required

- Now push the **display screen button** downwards to confirm.
- Rotate the display screen button to the top of the screen options,
    - And choose **Back** to go back to the homepage.

This brings us to the end of the task.

iii.) Expert guide for low complexity task

THE TASK (BUILD-PLATE)

What we are going to do right now is that, a student at HEC wants to come use the 3D printer later. So we have to check the build-plate

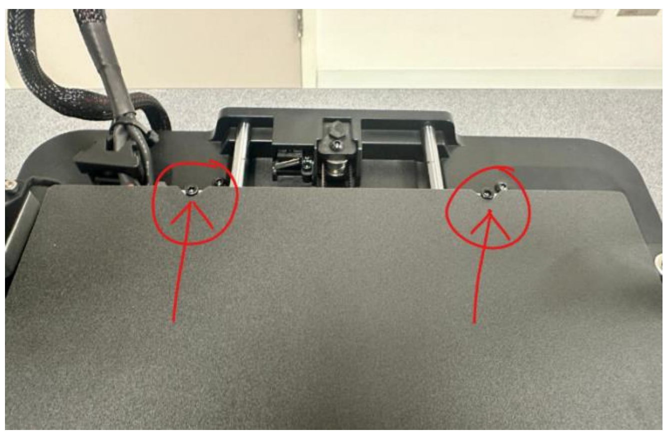
- To be able to move the plate, we need to adjust the **Extruder** to move up, for you to get enough space to remove the plate

- To adjust the **Extruder**, I need you to check the **Display Screen**.

- Rotate the button to highlight the "**Prepare**" option displayed ON THE MAIN MENU, and push the button down to select
- **If** you see "**Homing**" displayed on the screen, wait for the homing to finish.
- Anytime you see the **3D printer parts moving**, wait for it to stop.
- Rotate the display screen button to select "**Move**" from the options.
- Rotate the display screen button to select "**Move Z**" from the new options
- Now you can rotate the button again to your right (clockwise), to start moving the Extruder upwards.
- Stop rotating when the Move Z reading displays: **170**

- Now, you can proceed to remove the build-plate.
    - It is flexible and rests on the surface like a magnet
    - Hold the protruding parts and pull the plate upwards

- Take a look at the buildplate you are holding in your hands, to see if it looks okay.
- Finally, we are going to put the buildplate back in place.
- Slowly place it from the back into the two screws at the back of the desired position

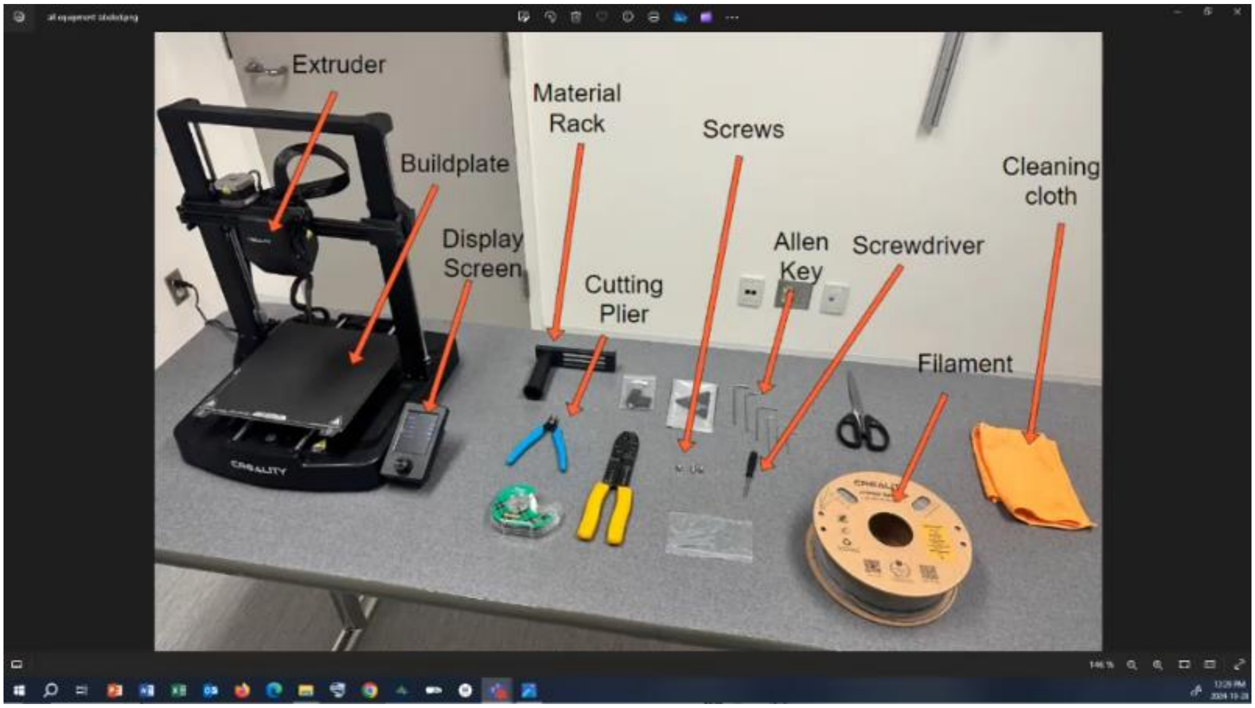


- And make sure all edges fit the surface well.

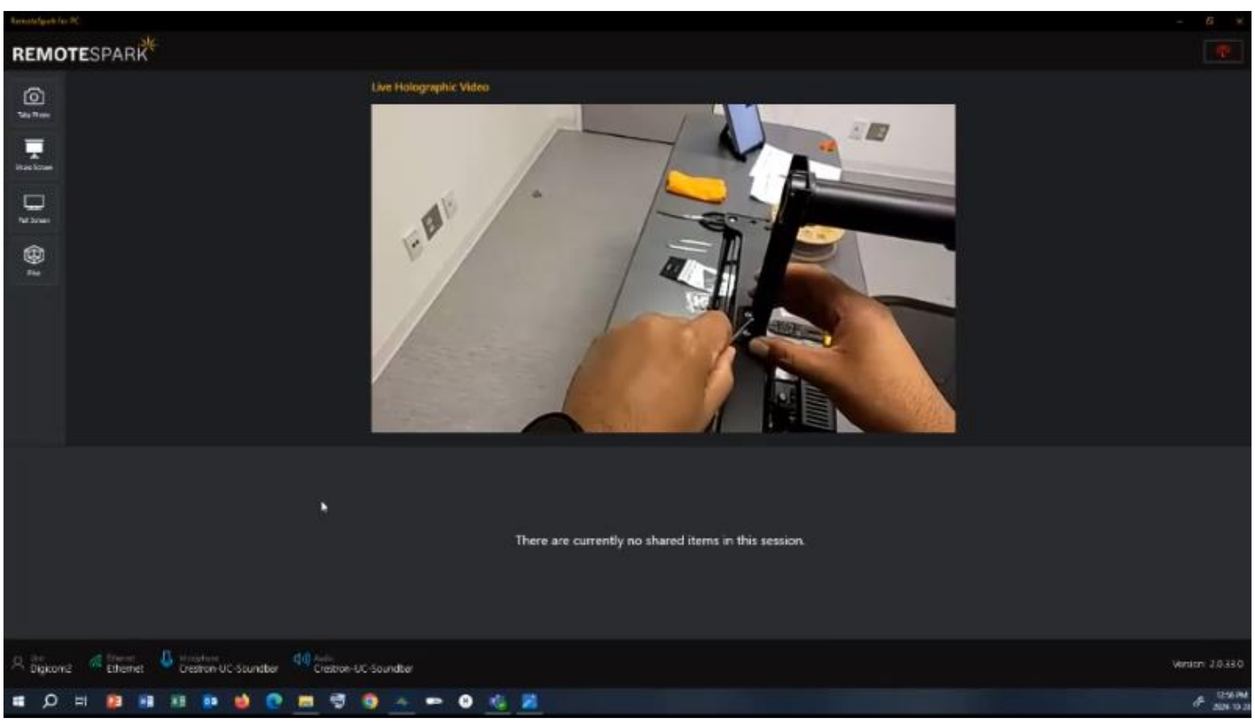
This brings us to the end of the task.

Appendix E. Screenshot of Expert's screen on MR technology and videoconferencing

i.) Left TV screen for expert:



ii.) Right TV screen for Expert on MR technology:



iii.) Right TV screen for Expert on videoconferencing: