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Knowledge Sharing with Augmented Reality

A Single Case Study of Remote Assistance in
a Chemical Production Plant

Kim Hovden Duong
Kristian Gravdal

Industrial Economics and Technology Management
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Supervisor: Alf Steinar Sætre, IØT

Norwegian University of Science and Technology
Department of Industrial Economics and Technology Management

PROBLEM DESCRIPTION

In the knowledge-driven economy characterized by digitalization and automation, tasks are becoming less repetitive and more complex, requiring more knowledgeable workers. Not being able to be an expert on everything at once, knowledge workers must continuously share their knowledge in order to solve the most complex problems. Furthermore, when knowledge is required on demand, sharing of knowledge is often necessary remotely. In this master thesis, we seek to determine in what ways Augmented Reality (AR) can be valuable as a communication technology to enhance knowledge sharing in remote assistance scenarios. This study is a qualitative, quasi-experimental study where we compare how a team of seven experts working in a chemical production plant share knowledge in remote assistance scenarios with and without AR.

PREFACE

This master thesis is the concluding work of our Master of Science degree at the Norwegian University of Science and Technology (NTNU). The thesis was written during Spring 2018, within the specialization of Strategy and International Business Development, at the Department of Industrial Economics and Technology Management. The thesis was written in collaboration with a large Norwegian chemical company with the goal of investigating the value of Augmented Reality as a technology. First, we would like to thank our supervisor Alf Steinar Sætre for his valuable guidance and feedback throughout the process. Second, we would like to thank our contact at the Chemical Co. for insightful discussions and the collaboration necessary to develop this thesis. Lastly, we would like to thank the seven engineers involved in the study at Chemical Co. for their time and contributions.

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Kim Hovden Duong and Kristian Gravdal

EXECUTIVE SUMMARY

The goal of this master thesis is to determine in what ways Augmented Reality (AR) is valuable for knowledge sharing in remote assistance scenarios. No person can know everything or be everywhere at the same time. Thus, sharing knowledge remotely is of importance to any knowledge-driven organization. Currently, most organizations share knowledge remotely through mobile phones, constrained to oral communication. Moreover, it is estimated that at least $31.5 billion is lost each year by Fortune 500 companies as a result of failing to share knowledge. Thus, we believe investigating new and innovative ways to share knowledge remotely can be valuable. AR is a technology that superimposes digital objects on top of the real world, introducing a new layer of communication.

Our findings indicate that AR can reduce uncertainty between an expert and a non-expert in a remote assistance scenario as they can share a visual representation of what the non-expert sees. This makes it easier for the non-expert to explain the problem as the need for a common language is reduced when he does not need to be as precise in his oral communication. The same yields for the expert, as he can directly guide with visual markers instead of using complex explanations the non-expert might not understand. This also makes the communication more effective. Furthermore, it also reduces the competency level requirements of a non-expert. Lastly, the use of AR can reduce cognitive load both for the non-expert and the expert as they can more quickly reach a common ground of understanding, also making it easier to get to the root of a problem.

The most significant challenge identified was using a handheld AR device. For the non-expert, having to film with one hand, perceive the expert's guidance through visual markers on the handheld device, listen to the expert's guidance, perform actions on a system and troubleshoot at the same time resulted in cognitive overload. Therefore, we suggest future research to use a head-mounted display which would give the non-expert the freedom to focus on receiving guidance as well as performing actions based on this guidance. This would also provide the expert with a continuous and more stable view of the work, enabling the expert to more accurately see what the non-expert sees.

SAMMENDRAG

Målet med denne masteroppgaven er å fastslå på hvilke måter Augmented Reality (AR) er verdifullt for kunnskapsdeling i fjernhjelp-situasjoner. Ingen kan vite alt eller være overalt til enhver tid. Dermed er ekstern deling av kunnskap viktig for enhver kunnskapsdrevet organisasjon. For tiden deler de fleste organisasjoner kunnskap eksternt med mobiltelefoner, begrenset til muntlig kommunikasjon. Videre er det anslått at minst 31,5 milliarder dollar går tapt hvert år av Fortune 500-selskaper som følge av manglende deling av kunnskap. Dermed tror vi at å utforske nye å og innovative måter å dele kunnskap eksternt kan være verdifullt. AR er en teknologi som superimposerer digitale objekter oppå den virkelige verden og dermed introduserer et nytt lag av informasjon.

Våre funn indikerer at AR kan redusere usikkerheten mellom en ekspert og en ikke-ekspert i en fjernhjelp situasjon, da de kan dele en visuell representasjon av det ikke-eksperten ser. Dette gjør det lettere for ikke-eksperten å forklare problemet da behovet for et felles språk reduseres når han ikke trenger å være like presis i sin muntlige kommunikasjon. Det samme gjelder eksperten, da han kan direkte veilede med visuelle markører i stedet for å bruke komplekse forklaringer som ikke-eksperten potensielt sett ikke forstår. Dette gjør også kommunikasjonen mer effektiv. Videre reduseres også kravet til kompetanse fra ikke-eksperten. Til slut kan bruk av AR redusere kognitiv belastning både for en ikke-ekspert og en ekspert, da de hurtigere kan nå en felles forståelse, som også gjør det lettere å komme til roten av et problem.

Den viktigste utfordringen som ble identifisert var bruken av en håndholdt AR-enhet. For ikke-eksperten å måtte filme med en hånd, oppleve ekspertens veiledning gjennom visuelle markører på den håndholdte enheten, lytte til ekspertens veiledning, utføre handlinger på et system og feilsøke samtidig, resulterte i kognitiv overbelastning. Derfor foreslår vi at fremtidig forskning tar i bruk hodemontert-AR, noe som vil gi ikke-eksperten friheten til å fokusere på å motta veiledning, samt utføre handlinger basert på denne veiledningen. Dette vil også gi eksperten en kontinuerlig og mer stabil oversikt over arbeidet, slik at eksperten mer nøyaktig kan se hva ikke-eksperten ser.

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LIST OF ABBREVIATIONS

AR	Augmented Reality
AV	Augmented Virtuality
ART	Augmented Reality Telementoring
CIS	Common Information Space
CoP	Community of Practice
MR	Mixed Reality
OELE	Open-Ended Learning Environment
PSE	Process system engineerning
RV	Reality-Virtuality
VIPAR	Visual Interactive Presence with Augmented Reality
VR	Virtual Reality

1 INTRODUCTION

In an economy characterized by hypercompetitiveness and automation, knowledge is recognized as a valuable intangible resource that is crucial for competitive advantage (Davenport & Prusak, 1998; Grant, 1996; Halawi, Aronson, & McCarthy, 2005). Furthermore, in the knowledge-driven economy, tasks are becoming less repetitive and more complex requiring more knowledgeable workers (Brynjolfsson & McAfee, 2012). Moreover, the human brain has a limited capacity to acquire, store and process knowledge, requiring knowledge workers to specialize in particular areas and becoming experts in their fields (Grant, 1996). To capitalize on their experts, organizations must consider how to transfer and share their knowledge when and where it is needed.

Knowledge sharing among employees, within and across teams allows organizations to exploit and capitalize on knowledge-based resources (Cabrera & Cabrera, 2005; Damodaran & Olphert, 2000; Davenport & Prusak, 1998). Research has shown that knowledge sharing is positively related to reductions in production costs, faster completion of new product development projects, team performance, firm innovation capabilities and firm performance (e.g., Arthur & Huntley, 2005; Collins & Smith, 2006; Cummings, 2004; Hansen, 2002; Lin, 2007; Mesmer-Magnus & Dechurch, 2009).

To promote knowledge sharing, organizations have invested considerable time and money into knowledge management systems which facilitate the collection, storage, and distribution of knowledge. Yet, despite these investments, it has been estimated that at least $31.5 billion are lost per year by Fortune 500 companies as a result of failing to share knowledge (Babcock, 2004). Research on why these knowledge management systems fail point to a gap between the information technologies used, and how organizational, interpersonal and individual characteristics influence knowledge sharing (Carter & Scarbrough, 2001; Malhotra, 2004; Voelpel, Dous, & Davenport, 2005).

To solve complex and context-specific problems, specialized knowledge that is difficult to transfer by means of written or oral communication, also known as tacit knowledge, may be needed (Polanyi, 1958, 1967). As this knowledge may reside in experts who cannot geographically or practically be available at every moment in time, providing assistance remotely may be favorable. The most commonly used tool for sharing knowledge remotely is the mobile phone. However, when remote knowledge sharing is constrained to oral communication, the knowledge sharing process may fail due to the inefficiencies of the mobile phone in conveying tacit knowledge. Augmented Reality (AR) is a technology that adds more layers of communication in comparison to the mobile phone. It does this by superimposing digital objects on top of the physical world, closing the gap between data and its context (Porter & Heppelmann, 2017). Knowledge sharing processes between an expert and a non-expert are often of an uncertain and ambiguous nature and according to media richness theory (Daft & Lengel, 1984), AR may perform better in such situations compared to the mobile phone as it can be considered a richer medium. Research on AR is most often concerned with the technical aspects of the technology, evaluating how it might improve quantitative measures such as speed and performance in performing tasks (Azuma, 1997; Billinghurst, Clark, & Lee, 2015; Craig, 2013; Van Krevelen & Poelman, 2010). At the same time, Billinghurst and colleagues (2015) point to a gap in the literature towards collaborative user studies, mentioning how only 10% of AR studies included user studies, and even fewer of those had a focus on how AR can be used to enhance collaboration.

In this master thesis, we address this gap in the literature by performing a qualitative, quasi-experimental study, comparing how a team of seven experts working in a chemical production plant share knowledge in remote assistance scenarios with and without AR. This master thesis is done in collaboration with a large industrial chemical company (Chemical Co.) to investigate the benefits and disadvantages AR for remote assistance, laying the groundwork for a more extended proof of concept.

The study builds on our own project report, written during the fall of 2017. In this project, report we sought to identify what makes AR valuable and how industrial companies can leverage that value. In determining the value of AR, we found that it has three core capabilities: (1) reducing cognitive load and enhancing cognition through information visualization (Card, Mackinlay, & Shneiderman, 1999; e.g. Porter & Heppelmann, 2017), (2) enhancing tacit knowledge sharing through collaboration (e.g., Ackerman, Dachtera, Pipek, & Wulf, 2013; Andersen et al., 2016; Karim et al., 2013; Ponce, Menendez, Oladeji, Fryberger, & Dantuluri, 2014), and (3) enhancing both individual and collective learning through contextualized knowledge, increased engagement and shared simulations (Antonioli, Blake, & Sparks, 2014; M. Bower, Howe, McCredie, Robinson, & Grover, 2014; Estapa & Nadolny, 2015; March, Sproull, & Tamuz, 1991; Wu, Lee, Chang, & Liang, 2013; Yuen, Yaoyuneyong, & Johnson, 2011).

To leverage the value of AR, the remote assistance use case was found to be the most value-adding use case as it incorporates all of the AR's core capabilities. Furthermore, remote assistance leverages AR as a tool for human-to-human interaction, not just human-computer interaction. A qualitative research approach was chosen take advantage of the uniqueness of AR, and to give us to flexibility to capture interesting emergent themes (Eisenhardt, 1989; Yin, 2009). By combining interviews with observations of how the team under study currently share knowledge remotely and comparing it with how AR affects the same process, we hope to be able to find what makes AR valuable in these scenarios. To guide our research, we have developed the following research question:

In what ways is Augmented Reality valuable for knowledge sharing in remote assistance scenarios

To address this research question we have sought to compare knowledge sharing in remote assistance scenarios with and without AR. Through an analysis of the empirical data, we have found the five themes: technological aspects, learning, competency level, mental models, and communication. These themes have been found to affect knowledge sharing with and without AR. By discussing these themes in relation to theory, we aim to determine in what ways remote assistance with AR can be valuable for knowledge sharing. This can be of high value to organizations who are dependant on sharing knowledge remotely, which encompasses organizations in all types of fields.

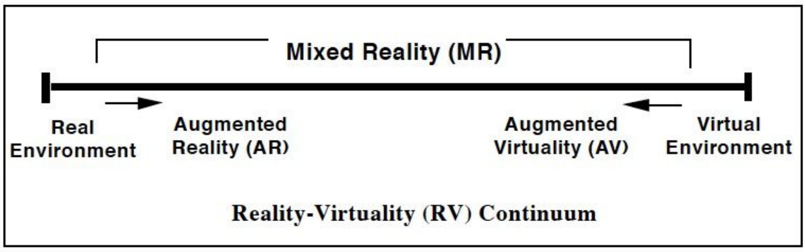
2 CONCEPTUAL BACKGROUND

In this chapter, we present a conceptual background for our thesis. We begin by defining AR, knowledge sharing and remote assistance. Thereafter, we will present a conceptual framework for knowledge sharing through AR remote assistance. This conceptual framework consists of the themes which emerged from the iteration between the literature review and the data collection.

2.1 Augmented Reality

The first substantial research article to mention the term AR was Milgram and Kishino's (1994) taxonomy of mixed reality virtual displays. Their taxonomy of Mixed Reality (MR) can be seen in the figure below.

Figure 1: Definition of MR (Milgram & Kishino, 1994)



Milgram and Kishino (1994) define MR as a technology that involves merging of real and virtual worlds somewhere along the Reality-Virtuality (RV) continuum which connects completely real environments to completely virtual ones. A completely virtual environment often referred to as a virtual reality (VR), completely immerses a user inside a synthetic environment. In this environment, the user cannot see the world around him or her. Milgram and Kishino use MR as the enveloping term where AR is a subset of MR where the real environment is being augmented, creating an augmented reality. On the other side of the continuum, augmenting a completely virtual environment with real objects creates an augmented virtuality (AV). Enveloping AR and AV as well as covering the gray areas between them, Milgram and Kishino (1994) use the term MR.

Building on this framework, Azuma (1997) goes on in his survey of augmented reality to define AR as any system that has the following three characteristics: "(1) combines real and virtual, (2) is interactive in real-time and (3) is registered in three dimensions" (Azuma, 1997, p. 356). Furthermore, Azuma (1997) describes AR as a technology that "allows the user to see the real world, with virtual objects superimposed or composited with the real world" (Azuma, 1997, p. 356). As such, AR supplements reality rather than completely replacing it as VR technology aims to do.

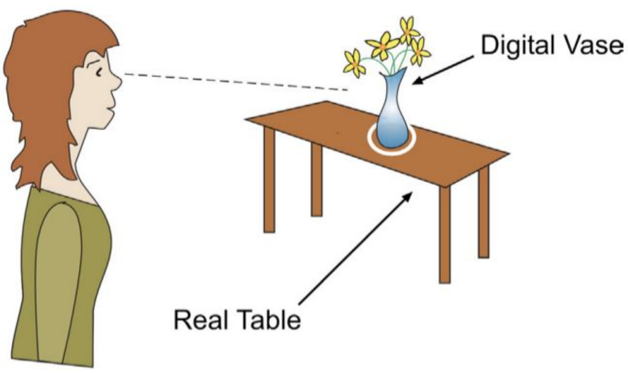
Since Azuma's (1997) paper there have been several articles aimed at surveying the technology and presenting a state of the art overview. Most notable are Azuma's (1997) follow-up "Recent advances in Augmented Reality", Van Krevelen and Poelman's (2010) "A survey of augmented reality technologies, applications and limitations" and finally, Billinghurst, Clark and Lee's (2015) "A Survey of Augmented Reality". Van Krevelen and Poelman (2010) expands on Azuma's (1997) definition by emphasizing three important aspects: "(1) AR is not restricted to particular display technologies such as head-mounted displays, (2) AR is not limited to the sense of sight and (3) removing real objects by overlaying virtual ones is also considered AR." (Van Krevelen & Poelman, 2010, p. 1).

In contrast to the academic publications cited above, Craig (2013) uses the medium of a book to further refine the AR characteristics defined by Azuma (1997) with four key aspects of AR: "(1) The physical world is augmented by digital information superimposed on a view of the physical world. (2) The information is displayed in registration with the physical world. (3) The information displayed is dependent on the location of the real world and the physical perspective of the person in the physical world. (4) The augmented reality experience is interactive, that is, a person can sense the information and make changes to that information if desired. The level of interactivity can range from simply changing the physical perspective (e.g., seeing it from a different point of view) to manipulating and even creating new information" (p. 16).

In regard to Craig's (2013) first key aspect, it is important to note that there is no restriction to what sense the digital information pertains to. It could be visual information, auditory information, or even information regarding smell, taste or touch (Craig, 2013). Furthermore, the information may be static such as text, numbers or a 3D model. It could also be dynamic, either in relation to time or based on sensors. Examples of dynamic in relation to time could be a clock where the arrows move with time or an animation that lasts a number of seconds. Additionally, dynamic in relation to sensors refers to a system that changes output based on sensor values. An example is the measurement of temperature where this dynamic information can be superimposed on the physical object one wishes to visualize the temperature of.

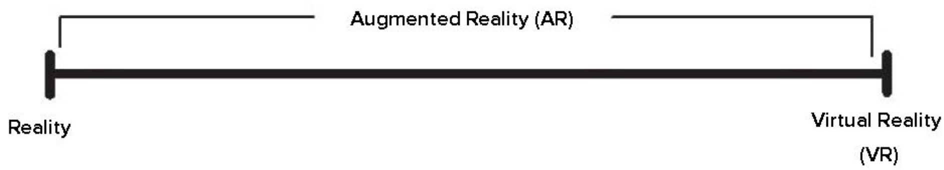
When digital information is superimposed on a view of the physical world, the user feels as though he or she is still in the physical world. This in comparison to VR, where the user is brought into another world by blocking out the physical world from the user's vision and replacing it with a completely virtual view. Another example of a technology that attempts to block out the physical world is a cinema experience. In this experience the lights are turned off, communication between viewers is discouraged and the big screen in front of the audience aims to fully engulf the audience in the cinematic experience. In an augmented reality, on the other hand, the physical and digital is merged in a way that the user still feels connected to the physical world. There are two ways an AR system handles this, either by projecting the digital on top of the physical or by capturing the physical world with a camera, merging the captured image with the digital information and then finally displaying it.

Figure 2: Illustration of digital information displayed in registration with the physical world (Craig, 2013).



Further considering Craig's (2013) second aspect of information being displayed in registration with the physical world, this can be illustrated in the figure above. This aspect is very important, as it pertains to how realistic the augmentation appears to the user. Digital information does not need to have a physical counterpart. Although in the figure above, a vase is represented digitally. Real objects are registered spatially and temporally. Spatially as in appearing in space, thus on earth adhering to gravity. Temporally as in adhering to time, if the user moves and looks at the vase from a different angle, then the vase still appears to be in the same place. If the vase is interacted with, either through direct or indirect interaction, then it should move accordingly. If the table in the figure above is moved, then the vase should move with it. These principles relate to Craig's (2013) third and fourth key aspects of AR.

Figure 3: Definition of AR on the Reality-Virtuality continuum of Milgram and Kishino (1994).



While Azuma's definition keeps things simple, this thesis builds on the refinements of Craig (2013) combined with the additional notes of Van Krevelen and Poelman (2010). With these constraints and in relation to Milgram and Kishino's (1994) taxonomy, AR is in this thesis considered to be everything in between complete reality and complete virtual reality. The figure above is a visualization of our definition of AR in relation to Milgram and Kishno's (1994) definition of MR as seen in figure 1.

2.2 Knowledge sharing

2.2.1 Definition of knowledge

To understand knowledge sharing, it is first beneficial to understand how knowledge is defined. In the literature there seems to be no clear consensual agreement as to the specific definition of this rather broad concept. One popular definition of knowledge is: "Knowledge is a fluid mix of framed experience, values, contextual information, and expert insights that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers. In organizations, it often becomes embedded not only in documents or repositories but also in organizational routines, processes, practices, and norms." (Davenport & Prusak, 1998, p. 4)

Further, Ackoff (1989) poem shines some light on the important conceptual differences between data, information, knowledge, and understanding: *"An ounce of information is worth a pound of data. An ounce of knowledge is worth a pound of information. An ounce of understanding is worth a pound of knowledge"* (p. 1). While moving from data to understanding, there is a gradual reduction of data and an accumulation of meaning as the essence of knowledge and understanding is gradually being uncovered. There are different criteria for sharing data, information, knowledge, and understanding. According to Ackoff (1989) information can be shared through who,- and what questions, knowledge can be shared through how questions and understanding can be shared through why questions. However, some questions are not easily answered when constrained to oral communication and may be difficult to store within documents or repositories. As Davenport and Prusak (1998) indicated in their definition of knowledge above, some knowledge is also deeply embedded in the mind and actions of the knower. This points to the existence of two different types of knowledge.

These two types of knowledge were first coined by Micheal Polányi to be explicit and tacit knowledge (Polanyi, 1958, 1967). Further, Nonaka and Takeuchi (1995) define explicit or codifiable knowledge as "knowledge that is transmittable in formal, systematic language" (p. 59). Explicit knowledge can be separated "from both the processes of its discovery and from the processes of its reattachment during implementation" (Spender, 1996, p. 65). Tacit knowledge, on the other hand, is not possible to separate from individuals and processes but is inherent in them. Tacit knowledge is "personal, context-specific and therefore hard to formalize and communicate" (Nonaka & Takeuchi, 1995, p. 59). Because tacit knowledge is hard to share through text or speech, there are many challenges in regard to sharing this type of knowledge.

The first challenge is the irreducible uncertainty connected to the undefinable nature of tacit knowledge (Polanyi, 1966). This is also called causal ambiguity where uncertainty in the contextual information needed to understand the tacit knowledge is also mentioned as a challenge (Szulanski, 1996). Secondly, tacit knowledge can also be embedded in different people as integral parts of a larger collectively understood knowledge. Therefore, the transferability of tacit knowledge is to a large degree a function of how collectively embedded the knowledge is (Haldin‑Herrgard, 2000; Spender, 1993; Szulanski, 1996). In other words, the more deeply embedded tacit knowledge is, the more difficult it is to share.

Furthermore, the importance of tacit knowledge in knowledge sharing is emphasized by many scholars, as the division between explicit and tacit knowledge are not clearly divided: "While tacit knowledge can be possessed by itself, explicit knowledge must rely on being tacitly understood and applied. Hence all knowledge is either tacit or rooted in tacit knowledge. A wholly explicit knowledge is unthinkable" (Polanyi, 1966, p. 7). This is line Jasimuddin, Klein and Connell's (2005) argument that there exists a graded continuum of knowledge, where explicit and tacit knowledge can be considered to be the endpoints on a spectrum of knowledge. Now that the concept of knowledge is clearer, the next sections will cover the relation between AR, explicit knowledge sharing, and tacit knowledge sharing.

2.2.2 Explicit knowledge sharing and its relation to AR

Explicit knowledge sharing has much relevance to AR, and the main reason for this is AR's potential to visualize explicit information contextually. One example is to use AR to visualize data such as temperature, pressure, air velocity, humidity and radiation gathered through sensors. It is then possible to for instance visualize when pump failures occur or monitor the humidity levels in agricultural fields. Another example demonstrated by Suma, Samson, Saranaya, Shanmugapriya, and Subhashri (2017) is to visualize movements of people and animals around vehicles with infrared radiation sensors. In the knowledge sharing literature, there are two terms that are important for understanding explicit knowledge sharing and its relation to AR. These are boundary objects and common information spaces (CIS) (Ackerman et al., 2013).

Star (1998) define boundary objects as objects that are “plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites” (p. 251). Common examples of predefined boundary objects are for instance maps or blueprints that support abstract and symbolic communication between groups (Star, 1998). Henderson (1991) presents a more flexible perspective of boundary objects as blank canvases to be filled with meaning by whoever uses or interprets it. Visualization is therefore often mentioned in boundary object research, as the flexibility of visual imagery can be used for creating and communicating complex ideas across social boundaries.

An AR platform can be seen as a boundary object because it represents a blank canvas in 3D that can be interacted with by multiple users in real-time. Managers and employees can imbue their own meaning and perception of their work into this canvas. Thus, this canvas of meaning can be shared between these two social groups to enhance cross-understanding and communication (Huber & Lewis, 2010). However, because boundary objects are deeply embedded within a specific personal and cultural world, some meaning will be lost when information crosses this boundary (Ackerman et al., 2013). In other words, the employee will never fully understand the world of the manager simply through a syntactical approach of sharing of explicit knowledge.

According to Carlile (2002), there are different ways of integrating knowledge when it crosses a boundary. If a sufficient syntax exists and is shared at the boundary, processing tools like shared repositories are sufficient for integration of knowledge. However, in the case where novelty, differences, and dependencies exist at one or both sides of a boundary, knowledge should be integrated through a semantic approach with standardized methods of translation and learning at a boundary. Furthermore, Carlile (2002) presents a pragmatic approach of knowledge sharing at boundaries, where knowledge is viewed as “localized, embedded, and invested in practice” (p. 445). Here, integration is based on the recognition that old knowledge has to be transformed at the boundary to be integrated. AR may be able to provide high-quality knowledge sharing across boundaries, independent of the complexity or the syntactical, semantic, or pragmatic circumstances that exist at a boundary. This is because

AR facilitates both the sharing of complex syntax as well as collective engagement in real-time practices. While boundary objects can act as a bridge between different social worlds, individuals throughout these social worlds can also be connected in common information spaces (CIS).

Even though individuals in a CIS have different backgrounds and perceptions of reality, they have reached a common agreement on the meaning of the information being maintained in a CIS (Schmidt & Bannon, 1992). The working environment in a CIS is open and highly collaborative where coordination and monitoring of information are shared (L. Bannon & Bødker, 1997). A good example of a CIS can be seen in industrial R&D communities working on radical innovations. These environments can be characterized as creative, open and chaotic. A shared understanding of what is being created often emerge from the individuals working together. In creative design processes, AR has made it possible for individuals to virtually work with digital prototypes in many more ways than what is possible with a physical prototype (Nee, Ong, Chryssolouris, & Mourtzis, 2012). Thus, because AR allows for individuals to communicate and collaborate in new ways, it may also enhance the process of establishing shared understanding within a CIS. Still, it can be difficult to pre-design a CIS. This is because a shared understanding of some specific type of knowledge emerges from the diversity of individuals present and their diverse backgrounds (Schmidt & Bannon, 1992).

With AR, one can share and visualize very complex explicit knowledge. However, even with the use of AR, explicit knowledge sharing is limited. This is because there is no one to explain what this complex knowledge means in real time. In other words, there is no collaboration or sharing of tacit knowledge. Explicit knowledge sharing through AR may, for instance, allow individuals to codify knowledge into a 3D boundary object or a 'blank AR canvas', as mentioned above. This boundary object can then be sent over a social boundary in order for another individual or a CIS to attempt to decontextualize this explicit knowledge themselves. The process of trying to understand this knowledge then happens without access to real-time communication with the source of this knowledge. This is not a shared AR experience in real time, but it is more like sending a very complex email.

In addition, explicit knowledge sharing is also limited by the paradox of explicit knowledge sharing and integration (Jasimuddin et al., 2005). This paradox is highlighted through the boundary object- and CIS concepts. According to Cabitza, Colombo, and Simone (Cabitza, Colombo, & Simone, 2013), this paradox exists because there is a contradiction between the openness and flexibility in CIS as a social system and the rigid routinization that is required to maintain boundary objects. On one hand, it is easier to absorb knowledge when one shares a common platform of understanding with the knowledge source Cohen and Levinthal (1990), and on the other hand it is necessary to access diverse knowledge across boundaries in to learn and generate new knowledge (Hargadon, 2002; Tortoriello & Krackhardt, 2010). By linking cognitive, social and structural activities, one is able to exploit an existing knowledge base. Furthermore, by reassembling existing ideas within a new context and a new boundary, one is able to generate new knowledge (Hargadon, 2002).

There have been identified many problems connected with knowledge sharing from explicit knowledge repositories. Ackerman and colleagues (2013) argue that the main cause of these limitations is that the explicit knowledge sharing perspective ignores important social contexts. Bannon and Kuutti (1996) support this by claiming that "information does not simply exist 'out there', but is produced by specific people in specific contexts for specific purposes" (p. 163).

In general, there are five main social issues connected with knowledge sharing and knowledge repositories (Ackerman et al., 2013): (1) motivation and incentives (Orlikowski, 1995; Schein & Van Maanen, 2013; Yang & Lai, 2010), (2) recontextualization or changing the context in which knowledge is reused (Ackerman & Halverson, 1999; Schmidt & Bannon, 1992), (3) authority, trustworthiness and reliability (Kankanhalli, Tan, & Wei, 2005; Van House, Butler, & Schiff, 1998), (4) politics (Gray, 2001) and (5) classification, updating and maintenance of repositories (Pipek, Hinrichs, & Wulf, 2003).

In Yang and Lai's (2010) article they discussed the problem connected to the maintenance of repositories by looking at the motivation of individuals to share knowledge on Wikipedia. Here, the different articles can be seen as boundary objects and the different individuals editing an article can be seen as a CIS. Some relevant questions that highlight a few of the limitations mentioned above would then be: who should be responsible for creating and deleting articles, and what are the motivations of people to stay in a CIS over a long period of time to keep articles up-to-date? This is an equally relevant issue within organizations as there are many problems and costs connected to keeping intranet content, or even AR content, up-to-date (Curry & Stancich, 2000).

By understanding the limitations connected to explicit knowledge sharing, organizations can instead realize the collaborative capability of AR by embracing the complex social dimension of tacit knowledge sharing. Thus, the sharing of tacit knowledge will be explored in more detail in the section below.

2.2.3 Tacit knowledge sharing and its relation to AR

Moving from explicit to tacit knowledge sharing, there is a shift in viewing technology as a means to create and manage repositories, to instead using technology as a tool to enhance tacit knowledge sharing (Ackerman et al., 2013). Nonaka and Takeuchi (1995) argue that socialization and shared experiences are critical for transferring tacit knowledge. Ackerman and colleagues (2013) support this by claiming that collaboration is a means to increase internalization of knowledge represented by experts. However, Ackerman and colleagues (2013) do not agree with Nonaka and Takeuchi's (1995) argument that tacit knowledge needs to be externalized to receive any value from it. Rather, the emphasis is on using technology to enhancing communication and aid in the process of finding experts. There most important concept explaining the social context of tacit knowledge sharing is communities of practice (CoP) (Ackerman et al., 2013).

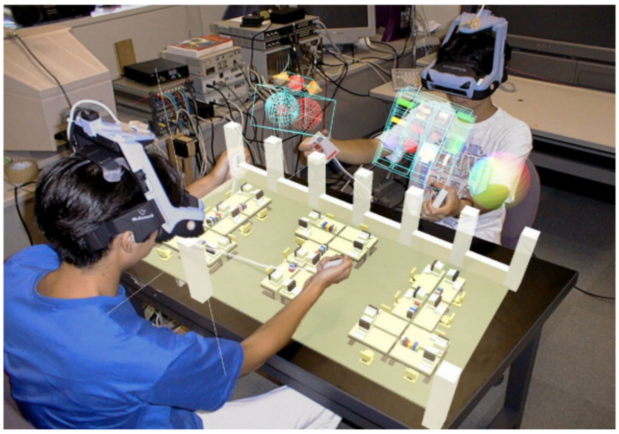
Communities of practices are heavily dependent on having a strong core group of motivated individuals. This is seen in Stuckey's (2004) meta-analysis of principles related to internet-mediated CoP development where some of the most important are: (1) communities should not be formed around applications, but around people, (2) communities require a passionate core group where the nature of voluntary participation is acknowledged and (3) the CoP should be sustained with the power of personal connections (p. 6-7). Examples of

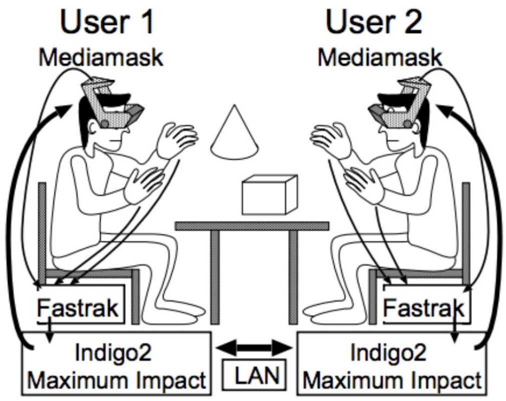
CoPs can include everything from individuals digitally collaborating on a design project to employees in training engaged in learning a particular skill. Thus, there is a concentration of knowledge at the core of these communities where the most engaged and passionate people gather. Technology should, therefore, be used to pull individuals from the periphery to the center where they can actively take part in the process themselves. Wenger, McDermott, and Snyder (2002) add that successful CoPs "build a fire in the center of the community that will draw people to its heat" and engage "members into more active participation" (p. 58). AR's collaborative capability is a good example of a technology being able to create such a fire.

AR's collaborative capability supports this process of creating an activity which people are able to join, observe and even interact with from all over the world. Several studies on collaborative AR substantiates this claim. For example, Wang and Dunston (2011) found that collaborative AR systems can improve performance time and mental effort in collaborative design tasks. Furthermore, Dong, Behzadan, Chen, and Kamat (2013) found that collaborative AR facilitates communication and discussion of engineering processes. Lastly, Poelman, Akman, Lukosch, and Jonker (2012) found improvements in mutual understanding between crime scene investigators with the use of collaborative AR. While these studies are fairly recent, research on collaboration in AR date back to the 1990s. Kiyokawa, Takemura and Yokoya (1999) found collaboration improvements even when hardware was cumbersome, and the interaction methods were far from intuitive.

The figure below is an example of Wenger and colleagues' (2002) fire, where two individuals gather around a common virtual LEGO practice with the help of AR's collaborative capability. This will enable them to internalize and learn the knowledge represented by the knowledgeable actors at the center and in the processes they engage in (Ackerman et al., 2013; Lave, Wenger, & Wenger, 1991; Weinberger, Stegmann, & Fischer, 2007).

Figure 4: A shared augmented reality of Virtual LEGO (Kiyokawa et al., 1999).





According to Dougherty (1992), one of the main advantages of a CoP, or a "departmental thought world" in her terminology, is that these communities develop "an internally shared system of meaning which provides a 'readiness for directed perception' based on common procedures, judgements, and methods" (p. 182). However, even though a CoP is grounded in an intrinsic harmony established from these systems of shared meaning, there are also some potential downsides to this. A consequence of directed perception is that the experts may selectively ignore or filter out essential information and insights (Dougherty, 1992). Another downside of the intrinsic harmony is that it may delude the experts of a CoP into believing that they know everything, which both makes the sharing of knowledge between CoPs difficult, as well as reduces the possibility of learning (Dougherty, 1992).

Whereas CoP only explains the inherent advantages in common practices, it is also important to be able to find an expert in a CoP when a problem arises. It is not necessarily given that one can easily find a person with the necessary cognitive ability and knowledge to solve a problem. Fitzpatrick (2003) calls this the "finding-out" process which involves getting connected with a personal source who holds necessary contextual knowledge (Fitzpatrick, 2003). This expert is able to de-contextualize the knowledge into integral subparts. Further, this enables the non-expert to more easily re-contextualize and learn this knowledge in its original context together with its sensemaking unit (Ackerman & Halverson, 1999). This is also called the descending method of knowledge sharing (Perret-Clermont & Bell, 1988). A good example of the descending method of knowledge sharing is the remote assistance use-case of AR. In this use case, it is possible for a user to stream his visual field to an expert.

The expert can then give guidance by talking while making annotations or even placing 3D graphics directly onto the user's visual field.

2.3 Remote Assistance

2.3.1 Defining remote assistance

Remote assistance is required when a person working on a problem, and anyone in his or her near vicinity, lack the knowledge or skills necessary to work with or solve the problem. Thus, the non-expert needs to be remotely assisted by someone who is able to guide and give them instructions on an unfamiliar or unknown problem. There are many different media in which remote assistance can take place, ranging from mobile phones, video teleconference, answering machines, and email. One example of a remote assistance scenario is when someone calls IKEA's service line to get assistance on building one of IKEA's products. Service lines often offer only oral remote assistance via for instance a mobile phone. Another example is when an expert surgeon remotely assists an inexperienced local doctor through a complex surgery. This assistance may also include other types of assistance where pictures and video are also shared. The medical industry has been using remote assistance technology for decades and is also at the forefront of trying to integrate remote assistance with AR technology. To better understand remote assistance and its potential in connection with AR, we look to the medical industry for insights.

2.3.2 Remote assistance in knowledge-intensive organizations

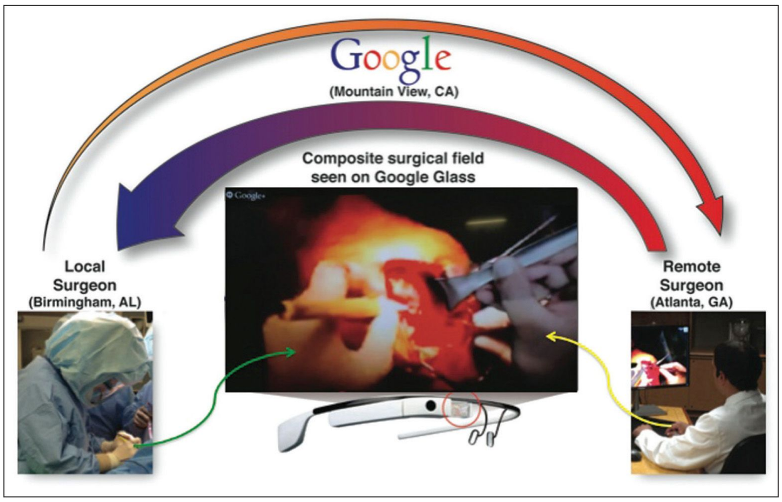
Knowledge-intensive organizations are "recognized as creating value through the use of advanced knowledge" (Alvesson, 2004, p. 29) and the "core of activities in these companies is based on the intellectual skills of a very large proportion of the labor force" (Alvesson, 2004, p. 17). From the context and underlying reasons for why remote assistance is needed in the medical industry, it can be appreciated that other industries like the one Chemical Co. is in, would benefit equally from remote assistance. A general problem in both industries is that inexperienced workers have an extensive demand for high-quality information from specialists.

In the medical industry, the supply of expert surgeons with high-quality information does not measure up to demand. Firstly, this is because surgery performance is very much correlated with technical acumen and clinical experience (Davis, Can, Pindrik, Rocque, & Johnston, 2016). Secondly, surgeries involve highly methodological and complex processes which preferably should be conveyed face-to-face as they often involve deeply embedded tacit knowledge (Gagliardi & Wright, 2010; Ponce et al., 2014). Still, logistics presents itself as a problem when bringing multiple experts together for one particular task or patient (Augestad et al., 2012). These reasons explain the scarcity of specialized surgeons in local or remote areas, why diffusion of this knowledge is often difficult and why there is a knowledge gap between central and geographically remote areas (Augestad & Lindsetmo, 2009; Cobey, 2010; Davis et al., 2016; Dawes & Lens, 2007; Polk, Vitale, & Qadan, 2009). These problems are not only relevant to the medical industry in isolation, as the essence of these problems refers to a lack of knowledge and difficulties with regards to knowledge sharing. To solve these problems, the medical industry has been exploring the possibility for bringing inexperienced and experienced surgeons together via telementoring technology.

Telementoring technology is used to enhance collaboration between remote expert surgeons and local inexperienced surgeons. Telementoring is a term that describes the use of technology as "tools to support for "interactive video and audio telecollaboration in which a remote surgeon provides guidance and training without directly performing the procedure" (Davis et al., 2016, p. 2). Research in this field has been conducted for a long time, and the first telementoring open heart surgery was performed in 1960 (Augestad et al., 2012).

As the telementoring field has evolved, it has adopted more technologies making the AR experience more authentic. Together with audio and video advancements over the years, the communication- and cooperative aspects of telementoring has been enhanced with the use of different telepointer tools such as cursors, lasers and sketching pointers (Ereso et al., 2010; Karim et al., 2013). In Augestad and Lindsetmo's (2009) review, they showed that it was common for the remote participants to augment their cursors onto the visual field of the local surgeon. Furthermore, Ponce and colleagues (2014) combined visual interactive presence with AR (VIPAR), adapted to Google Glass as seen in the figure below. VIPAR makes it possible for remote surgeons to be present in a local surgeon's field of vision and for instance demonstrate complex surgical procedures (Davis et al., 2016). Andersen and colleagues' (2016) study especially highlight the interactive features of VIPAR systems. With a touch-based system, they were able to create, modify and delete different annotations which were attached to specific objects and locations with computer vision algorithms (Andersen et al., 2016).

Figure 5: AR surgical field view using Google Glass (Ponce et al., 2014).



Telementoring and VIPAR have in general been concluded to be invaluable for intraoperative guidance and surgical education (Davis et al., 2016). In Augestad and colleagues' (2012) comprehensive review of surgical telementoring research, they found that it had a positive impact on education and that 83% of the 180 surgeons had reported satisfaction with telementoring technology. In Vera, Russo, Mohsin, and Tsuda's (2014) study on augmented reality telementoring (ART), they showed that this system would lead to significantly faster learning and skill acquisition compared to traditional telementoring. Andersen and colleagues' (2016) results showed that ART leads to greater accuracy and fewer focus shifts, but also slightly increased the time to completion, even on tasks that were previously unfamiliar to the participants. The importance of having guidance and expertise integrated into the operative field instead of having to consume, contain and translate 2D information onto a 3D context was especially highlighted by Andersen and colleagues (2016) to improve performance. In Ponce and colleagues' (2014) study with Google Glass as seen in the figure 5, the remote surgeon reported that it felt natural to augment his hand onto the visual field of the local surgeon and that this allowed him to give more detailed guidance. This substantiates the enhanced tacit knowledge sharing potential of AR. Many pre- and postoperative benefits have also been reported, such as ongoing guidance and training as well as improvement of evaluation and management (e.g., Davis et al., 2016; Duchesne et al., 2008). Lastly, there have been many researchers emphasizing the benefits of portable, wearable devices and AR technology over the traditional telecaster technology (Andersen et al., 2016; Hashimoto, Phitayakorn, Fernandez-del Castillo, & Meireles, 2016; e.g., Ponce et al., 2014; Vera et al., 2014).

2.3.3 AR as a remote assistance medium

The degree to which knowledge is shared and deeper understanding is conveyed is dependent on the richness of the communication technology (Daft & Lengel, 1984). Because AR is a communication technology, it is pertinent to look at remote assistance in terms of media richness. Rich communication media facilitates the processing of ambiguous subjective information by reducing divergent frames of reference and interpretations. Stephens and Sætre (2004) summarize the characteristics of rich communication media by their capacity to: (1) transmit signals such as voice intonations and nonverbal cues, (2) facilitate immediate feedback, (3) tailor messages to the real-time context, and (4) facilitate communication with ambiguous, conversational language. Other relevant factors that influence the richness of a medium is its capacity for conveying presence (Short, Williams, & Christie, 1976), the number of senses involved, and language variety (Daft & Lengel, 1984). On the other hand, a lean medium which is low in richness possesses only a minimum of these characteristics (Stephens & Sætre, 2004). Consequently, AR can be regarded as a rich communication medium as it conveys presence by providing a live audio and video feed, and by facilitating in the communication of complex tacit knowledge with the aid of visualizations. In this way, AR may help the people who communicate to more easily converge on a shared understanding of a particular type of information.

Different remote assistance media can be ranked according to their richness. Rice (1993) argued that there is an increase in richness as one progresses from written texts (e.g. electronic mail, and text messages), to audio (e.g mobile phone, and voicemail), to video (e.g. desktop video, and video conferencing), and then to face-to-face. This is a common way of ranking media using lean-to-richness scales (Short et al., 1976). Furthermore, to determine which media is best suitable for a certain type of communication, one must find out the degree of 'equivocality' of the information that is to be shared. Equivocality refers to both the uncertainty and the ambiguity inherent in the information. Uncertainty is reduced simply by gathering more information, while a reduction in ambiguity requires that one interacts and communicates directly with another person (Stephens & Sætre, 2004). Thus, lean media are suitable for reducing uncertainty, while rich channels are suitable for reducing ambiguity (Stephens & Sætre, 2004).

In the table 1 on the next page, Clark and Brennan's (1991) framework for communication media is adapted to fit with the AR context. The original model describes the different constraints connected to different remote assistance media, but it is here adapted to present a framework for how to measure different types of richness in a medium. A refers to the expert, B refers to the non-expert, and C refers to a person not relevant for A and B's knowledge sharing process. In the third column, AR remote assistance is analyzed for each richness factor.

Table 1: AR as a remote assistance medium. Adapted framework from Clark and Brennan (1991) to fit remote assistance with AR.

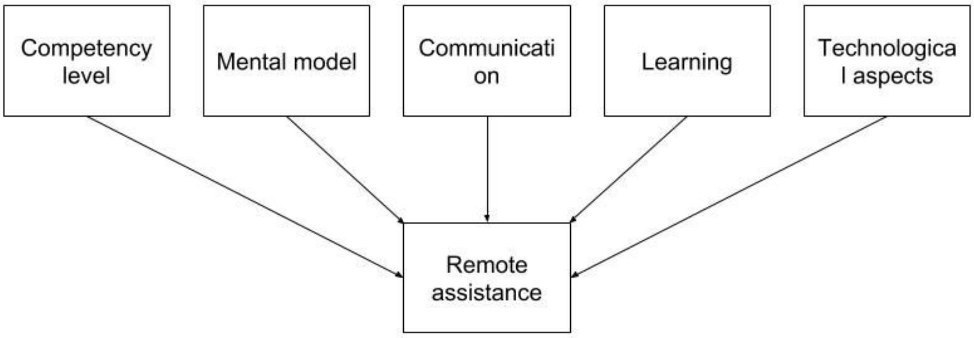
Richness factor	Description	Remote assistance with AR
Copresence	A and B share the same physical environment	A and B can see what B is doing and also to some degree see what B is looking at. The feeling of copresence will be a determined by the richness of the AR medium.
Visibility	A and B are visible to each other	Because B is streaming his visual field either from a head-mounted or handheld AR device, A will be able to see the lower parts of B's body and what activities B is engaging in. B can only see a digital representation of A's thoughts through A's augmentation of B's visual field.
Audibility	A and B communicate by speaking	With AR, A and B are able to hear each other just as well as as oral-based remote assistance. A might to a larger degree understand more deeply embedded tacit knowledge in B's oral utterances by combining this with the observation of B's actions and body language.
Cotemporality	B receives at roughly the same time as A produces	In normal face-to-face communication there is often a small delay before what is being communicated by A is understood by B. However with AR, there is also the possibility of visual communication, which may increase cotemporality due to more tacit knowledge being shared.

Simultaneity	A and B can send and receive at once and simultaneously	Real-time visual communication features enables B to see where A is pointing moment by moment through augmentation of B's visual field. However, at the expense of a view of the work, one is not able to view the face with AR. Therefore, it is not possible to get simultaneous feedback from facial expressions such as B smiling as a reaction to one of A's utterances.
Sequentiality	A's and B's turns cannot get out of sequence	Sequentiality is much more important with AR compared to for instance email. If C suddenly interrupts either A or B when they are trying to establish a common ground in B's visual field, this will intervene, if not disrupt this process completely. With email, irrelevant interruptions in between messages will not affect the quality of the common ground established.
Reviewability	B can review A's messages	Even though what is being said will quickly fade away, there is a possibility for both A and B to leave text notations or symbols behind as contextualized objects that can later be reviewed in AR.
Revisability	A can revise messages for B	With AR, A cannot directly edit or revise what B has uttered either as contextualized text annotations or as the contextualized visual highlighting. However, A can indirectly revise this by telling B to move, edit or delete these objects.

2.4 A conceptual framework: Knowledge sharing with AR

In the following section, we will explore the themes which emerged from the iteration between the literature review and the data collection. These themes can be seen in the figure below.

Figure 6: Conceptual framework.



2.4.1 Competency level

Competency level refers to the level of prior knowledge and experiences the individual has, which affects many other important knowledge-sharing characteristics like cognition, communication, knowledge recollection, and absorptive capacity (Cohen & Levinthal, 1990; Draganidis & Mentzas, 2006). For instance, competency level affects the ability to acquire new knowledge, recognize its value and apply it in a new context (Cohen & Levinthal, 1990). One reason for this is that the concepts and patterns already stored in the memory increase the chance of creating associative links with new information about similar concepts (Bower & Hilgard, 1981). As a consequence, this puts emphasis on the non-expert's competency level when receiving knowledge from an expert with AR remote assistance. Competency level will also determine the collective problem-solving capacity of the non-expert and expert.

How much prior experience both the non-expert and the expert has had in different remote assistance problems, will to a large degree determine how well they will be able to systematically try to solve a new problem. This is in line with Kuhn and Fleck (1979), who argue that prior knowledge impacts the cognitive content and approach to new contexts. Additionally, a second order effect of increased competency is increased acquisition of problem-solving capabilities (Cohen & Levinthal, 1990). However, the question of prior knowledge and competency level is not just about the number of previous experiences with different problems, but also how deeply embedded the knowledge is. Because tacit knowledge has the inherent features of irreducible uncertainty and causal ambiguity this makes it more difficult to use previously acquired tacit knowledge (Polanyi, 1966; Szulanski, 1996). This is in line with Stephens and Sætre (2004) who state that by gathering more information one can reduce the uncertainty in tacit knowledge, and by communicating directly with other persons one can reduce the tacit ambiguity. However, the uncertainty can only be reduced to a certain limit, and the ambiguity can only be reduced as far as the richness of the communication medium allows for. Thus, depending on how deeply embedded the tacit knowledge is, this may make it hard to replicate and use the knowledge in a new context.

It is not just the level of competencies that are important in knowledge sharing, but also the awareness of the other's competency level. According to (Boland & Tenkasi, 1995), the awareness of what others know is the first step in enhancing interaction in communities of knowing. Furthermore, the capacity of adopting the perspective of others is essential for collaboration, coordination, and communicative competence (Krauss & Fussell, 1991; Rommetveit, 1980). This kind of cross-understanding has been found to impact performance and learning to a large degree (Huber & Lewis, 2010). Consequently, if the expert is not aware of the non-expert's competency level while remotely assisting him or her, the barriers for knowledge sharing will be higher. For instance, it will be more difficult to notice the dissimilarities in their understanding and thus make it harder for the expert to precisely depict and share his unique knowledge.

2.4.2 Mental Model

The concept of mental models is crucial for knowledge sharing, mental models have been defined as “dynamic, simplified, cognitive representations of reality that team members use to describe, explain, and predict events'' (Burke, Stagl, Salas, Pierce, & Kendall, 2006, p. 1199). Mental models are developed because of the constraints concerning individual’s cognitive capacity. Porter and Heppelmann (2017) note that “the ability to absorb and process information is limited by our mental capacity”, and they go on to define the demand on mental capacity as cognitive load (p. 5). These constraints and limitations are also connected to concepts like bounded rationality, errors of judgment, uncertainty, and illogical thinking (Kahneman, 2011). Furthermore, the construction of a mental model is a result of an incremental process with several levels of iterations (Albrecht & O’brien, 1993). Consequently, only a subset of the information available at a given time will be used to construct knowledge and will then be used to facilitate the process of integrating new information into the existing mental model (Albrecht & O’brien, 1993). Hence, mental models will only represent a fraction of reality and will be colored by an individual's subjective interpretation, experience, and perspectives. If individuals who collaborate possess divergent mental models and large differences in subjective interpretations, this will reduce the quality of communication (Boland & Tenkasi, 1995). Therefore, shared mental models are important in communication.

A shared mental model refers to the commonality between factors such as language, thought worlds, perspectives, culture, knowledge, cognition, methodology, and experiences between people who collaborate and communicate with each other. Thus, shared mental models are common within departments because here the employees often share similar perspectives, experiences, and knowledge bases. In this way, individuals within a specific community of practice, serve as a good example of individuals who to a larger degree share mental models. Furthermore, Mathieu, Heffner, Goodwin, Salas, and Cannon-Bowers (2000) states that the function of shared mental models is “to allow team members to draw on their own well-structured knowledge as a basis for selecting actions that are consistent and coordinated with those of their teammates” (p. 274). This is also in line with Huber and Lewis’ (2010) cross-understanding construct, which refers to different individual's understanding of each other's mental model. The concept of shared mental models fit closely with the concept of communication with AR, because the mental model that previously was only in the minds of the non-expert and the expert, will now to some degree be automatically communicated between them as a shared live video and with digital markers. Consequently, for meaningful and effective knowledge sharing to occur, the more that is shared between the non-expert and the expert of factors such as knowledge, cross-understanding, language, and visual fields, the better.

Because the environment and the context affect and shape mental models, it is also of relevance to see how the external visual context affects cognition. The correlation between visualization and cognition has been extensively researched (Card et al., 1999). Information visualization is often defined as the "use of computer-supported interactive visual representations of abstract data to amplify cognition" (Card et al., 1999, p. 7). Furthermore, external cognition is defined as "the interaction of cognitive representations and processes across the external/internal boundary in order to support thinking" (Card et al., 1999, p. 7). There have been many findings supporting the cognitive benefits of visualizing information (Kirsh, 2010; Liu & Stasko, 2010; Scaife & Rogers, 1996). Porter and Heppelmann (2017) note that because AR allows people to process the physical and digital information simultaneously, this eliminates the need to mentally bridge the two. Consequently, digital information visualization with AR will not only reduce cognitive load but also help individuals to access and release a wealth of unique capabilities (Porter & Heppelmann, 2017). Card and colleagues (1999) categorizes these benefits accordingly: (1) increased perceptual resources such as processing and memory, (2) reduced search for information, (3) enhanced pattern recognition and (4) enabled perceptual- inference and monitoring. Furthermore, Porter and Heppelmann (2017) argue that the possibilities created by AR are that one does not have to consume, contain and translate 2D information to use it in the real world, in a 3D context. By applying the information in the context where it is needed, the cognitive distance and the cognitive load can be reduced. Porter and Heppelmann (2017) define cognitive distance as "the gap between the form in which information is presented and the context in which it is applied" (p. 5). By taking information that has traditionally been presented as text or images on a screen and visualizing it on top of the object one wishes to know information about, information is presented in context and thus the cognitive distance is reduced. Thus, as cognitive distance and cognitive load are reduced, an individual may be less restricted by his limited mental model, biases, and interpretations.

2.4.3 Communication

For high-quality communication to occur, both the recipient and the sharer of knowledge must coordinate the knowledge content and the process in which it is shared. This is in line with Clark and (1991) (1991) theory of grounding in communication. Coordination of content cannot happen before a common ground of information, knowledge, beliefs, and assumptions are established. Furthermore, coordination of the process requires that both parties moment by moment update their common ground. Coordination of content is not only possible to improve by attempting to become an expert in the other individual's domain of knowledge or by understanding most of each other's mental models as possible. Instead, Paletz and Schunn (2010) emphasize that "enough of a shared language [must] exist to facilitate teamwork" (p. 87). This indicates the importance of shared language, which is found to have a significant positive impact on knowledge sharing (Chang & Chuang, 2011). Furthermore, AR can be used to reduce ambiguity by enhancing the coordination of the process. Daft and Lengel (1984) supports this by arguing that rich communication media can reduce ambiguity by reducing divergent frames of reference and interpretations. These divergent frames of reference can in the processual context be understood as divergent visual fields. For instance, during physical collaboration, the non-expert and the expert may collaborate on the same physical object, but their visual fields are not completely synchronized. This also applies to the time and quality of shared awareness. People may be present together physically, but may not be equally focused on the task they are supposed to collaborate on. However, with AR, the expert and non-expert share both a visual field and an awareness to a much larger degree. Thus, lack of a shared awareness and divergent visual fields and can also be understood as a lack of a common ground in communication.

While the concept of a common ground in communication includes concepts like shared mental models, it also extends beyond it. According to Clark and Brennan (1991), this is because these concepts refer to the coordination of content, but not necessarily the coordination of the process. A shared mental model can be established prior to communication by learning about the other's culture, knowledge, language and so on, whereas a common ground is also established during communication by reducing divergent frames of interpretation and by sharing visual fields and awareness.

2.4.4 Learning

Knowledge sharing and learning are two deeply interrelated processes. Moreover, AR provides a substantial potential for education, learning and creative inquiry (Johnson, Levine, Smith, & Stone, 2010). Johnson and colleagues (2010) explain this in the fact that AR has a "strong potential to provide both powerful contextual, on-site learning experiences and serendipitous exploration and discovery of the connected nature of information in the real world" (p. 21). Furthermore, in learning contexts like these, it is possible to learn by actively being engaged in a process of sharing tacit knowledge, skills, and insights (Verburg & Andriessen, 2011).

Learning with AR has proven to be helpful for memory, motivation, and performance. Compared to traditional learning methods, students who use AR are more likely to retain knowledge and be able to connect it to real-world experiences and applications (Antonioli et al., 2014; Wu et al., 2013). Premadasa and Bhatia's (2013) findings support this as students prefer problems that they can relate to. The Royal Ontario Museum hosts AR field trips for students where the students can experience famous historical wars and speeches as if they were present there themselves (ElShafie, 2015). Antonioli and colleagues (2014) found that the use of AR in education demonstrated a higher degree of motivation and engagements in students. Estapa and Nadolny (2015) found similar results in their study on the use of AR for lessons in mathematics. The latter study also found an increase in academic performance.

Even though AR can contribute to learning in many ways, there are still requirements for individuals attempting to learn with the support of AR technology. Szulanski (1996) explains the reasons for the lack of retentive capacity in connection with a lack of persistence and motivation. Salomon (1985) supports this as he argues that internalization of knowledge is strongly tied to the degree in which the learners willingly engage in the technology. This substantiates the relevance of exploring research into learning requirements and theory about learning environments.

The learning environment in which AR is applied can be understood as an open-ended learning environment (OELE) as Land (2000) presents in her article. According to Land (2000), there are three main characteristics of OELE: (1) using visualizations to facilitate experimentation, (2) using authentic contexts to establish the link between explicit knowledge and experience, and (3) using resource-rich environments to foster learning-centered inquiry. Land (2000) has also identified limitations and paradoxes in relation to each of these characteristics. In this respect, she presents three cognitive requirements for the learning individuals to support the learning process. The characteristics and limitations Land (2000) has identified are similar to the ones presented in the previous sections, which makes OELE a good theoretical framework for the AR learning environment.

First, in relation to visualization, there are “limitations of novices to accurately perceive and interpret visual cues” (Land, 2000, p. 65). This is mainly because novices do not necessarily know which visual cues are most relevant and thus pay more attention to superficial visual cues (Chi, Feltovich, & Glaser, 1981). Land (2000) therefore proposes the following cognitive requirement: “Generate, test and refine theories, based on supporting evidence perceived from visual displays” (p. 65). Secondly, there are two limitations in relation to learning in an authentic context. The first is concerned with trying to learn new things while referencing incomplete past knowledge (Land & Hannafin, 1997). The second is concerned with justifying simple theories based on imperfect observations and experiences (Brickhouse, 1994). Land (2000) therefore proposes the following cognitive requirement: One should voluntarily make attempts to “integrate new and prior knowledge” with analogical reasoning and actively challenge naive preconceptions (p. 64). Thirdly, in relation to the limitation of resource-rich environments, there is a dilemma called the metacognitive knowledge dilemma. This dilemma revolves around “monitoring learning in the absence of domain knowledge” (Land, 2000, p. 72). Domain knowledge here refers to the knowledge which is developed by specialists and experts within that field of knowledge. Hill and Hannafin (1997) argue that in the situations without access to domain knowledge, it may be difficult to refine one's own strategies even though they are inefficient. Thus the learner should be able to “generate and refine questions, interpretations, and understanding based on new information", which places importance on metacognitive capabilities and comprehensive monitoring (Land, 2000, p. 64).

The above requirements explain learning on a cognitive level. However, there is also a question with regards to the frequency and availability of experiences one can learn from. March and colleagues (1991) point out that the problem with learning from experience is that history provides few samples of critical events from which one can learn from. Organizations learn and "expand their comprehension of history by making experience richer, by considering multiple interpretations of experience, by using experience to discover and modify their preferences, and by simulating near-events and hypothetical histories" (March et al., 1991, p. 5). March and colleagues (1991) argue that insights should be extracted from intensive examination of the experience through an analytical approach and in this way expand the richness of that experience. However, AR has the potential to expand the richness of experience in many more ways than what is possible through March and colleagues' (1991) intellectual and post-analytical approach. AR can create a shared simulation of these events so that people may actually experience it themselves, and in this way experience what their interpretations, preferences, and actions would actually be like. A simulation "entails the representation of a phenomenon that might include an activity, experience or event which is as realistic as possible" (Felton, Holliday, Ritchie, Langmack, & Conquer, 2013, p. 536). An example of this may be the case of the extreme situation of a fire or an explosion within an industrial chemical plant. Here, it may be hard to follow March and colleagues' (1991) analytical and speculative approach on how they would react, feel, and think in that extreme situation. Thus, because AR has the potential to provide a platform for simulation of authentic real-world incidents, it enhances the process of "learning from one or fewer samples" as described in March and colleagues' (1991) article.

2.4.5 Technological aspects

In relation to the technological aspects of AR, Martínez, Skournetou, Hyppölä, Laukkanen, and Heikkilä (2014) identified the most important technological limitations of AR to be tracking inaccuracies, constrained computational power and information overload. As the most advanced computer vision algorithms for tracking requires vast amounts of computational power, tracking is the bounding factor when considering limited computational power. Porter and Heppelmann (2017) note that affordable, lightweight and high-performance smart glasses are still a barrier to widespread adoption of AR. Furthermore, in a review of maintenance applications with AR by Palmarini, Erkoyuncu, Roy, and Torabmostaedi (2018), they note that head-mounted displays for industrial maintenance use cases have too much latency in them, making them not yet suitable for the real world. This latency can be attributed to a lack of computational power as well as network latency.

According to Moore's law which states that transistors in computer chips double every two years (Moore, 1995), the limited computational power of AR devices will be overcome with time. However, recent years have shown that Moore's law is coming to an end (Waldrop, 2016). Still, while transistor count might not double every two years, innovation in the semiconductor industry is not likely to stop. There are several promising technologies that could renew the law. For instance quantum computing and use of other materials such as graphene (Waldrop, 2016).

Tracking inaccuracy is connected to Azuma's (1997) definition of an AR system being registered in three dimensions. It relates to the ability to anchor virtual content on top of the real world, augmenting the view in such a way that it appears to be a part of the physical environment. To accurately do this, the system needs to know the position and the orientation of the viewer in relation to the anchor. Billinghurst and colleagues (2015) outline the different tracking technologies that have been used for AR systems as magnetic tracking, vision-based tracking, inertial tracking, GPS tracking and hybrid tracking. These tracking systems have been used in isolation, but also in combination through hybrid tracking.

Billinghurst and colleagues (2015) go on to note that vision-based tracking has been the most used form of tracking in AR systems. Vision-based tracking uses computer vision algorithms to understand the environment in which it sees through a regular camera. In recent years, the computer vision field has seen drastic improvements with the advent of machine learning algorithms applied to the problem of computer vision. These machine learning algorithms have made use of artificial intelligence methods such as deep convolutional neural networks that were ignored by the computer vision community for decades (LeCun, Bengio, & Hinton, 2015). The results can be seen in the newly released AR-Kit and AR-Core software development kits for iPhone and Android respectively. These software development kits enable smartphones without dedicated depth sensors to give accurate tracking in real-time through a combination of a smartphone's internal sensors and its high-performance cameras. In other words, a hybrid tracking system.

To provide persistent objects that appear photo-realistic in the given environment, both Apple and Google have applied two fundamental techniques. First, motion tracking in three dimensions allows objects to stay or move in three dimensions, relative to the user in a persistent and coherent way. Second, environmental understanding and light detection allow surfaces and light to be detected to place or move objects realistically in real time (Ling, 2017). Previously, these capabilities have only been possible with additional hardware such as depth-sensing cameras (Sweeney, Flynn, Nuernberger, Turk, & Höllerer, 2015). Still, Ling (2017) notes that tracking with AR-Kit and AR-Core has limitations in terms of occlusion detection and the capability to stay persistent in the same location when digital objects are placed and then viewed from different angles. In terms of head-mounted displays with depth sensors, Evans, Miller, Pena, MacAllister, and Winer (2017) recently evaluated an assembly application using HoloLens. They found that tracking inaccuracy is still a limitation in terms of deployment in a factory assembly setting.

Van Krevelen and Poelman (2010) mention information overload as critical in designing AR user interfaces such as AR remote assistance interfaces. Martinez and colleagues (2014) substantiate this claim by mentioning that the amount of information to be displayed in the augmented view should not exceed the needs of the user. Failure to consider information overload can lead to the user experiencing a state of information anxiety. Bawden and Robinson (2008) define information anxiety as "a condition of stress caused by the inability to access, understand, or make use of necessary information" (p. 185). As information anxiety can be hazardous in a high-risk environment, AR systems should be designed as to not lead to information overload should it be usable in high-risk environments.

3 METHODOLOGY

In this chapter, we present the methodology of this master thesis. This includes the research design, data collection, data analysis. Finally, the chapter is concluded by assessing the quality of our study.

3.1 Research design

We designed a qualitative, quasi-experimental case study. As little research has been done on AR remote assistance, and specifically in relation to knowledge sharing, a qualitative research approach was the most appropriate. Because the research topic is not understood properly, the data is likely to be imprecise. Thus, the flexibility provided by qualitative techniques would be beneficial (Yin, 1994). Glaser and Strauss (1967) also suggest using a qualitative approach when the analytical categories are expected to change during the research process. This flexibility is regarded by Eisenhardt (1989), not as a license to be unsystematic, but as *controlled opportunism* which allows the “researchers to take advantage of the uniqueness of a specific case and the emergence of new themes to improve resultant theory” (p. 539).

The aim of our case study is to explore the effects of AR remote assistance on knowledge sharing. Our research is simultaneously of an exploratory nature as well as having elements of testing existing theory. Thus, we constantly iterated between theory development, data collection, and data analysis. Considering the novelty of AR remote assistance we wanted to “develop sharper and more insightful questions” into this research topic, which supports the choice for conducting an exploratory case study (Yin, 1994, p. 9). This would argue for the use of Glaser and Strauss’ (1967) strategy of following a more emergent and loosely structured approach of inductively constructing a “grounded” theory from raw empirical data. However, as mentioned, we also came to this research project with some orienting ideas: we wanted to specifically look at behavior related to knowledge sharing before and after the introduction of AR into the case study. In this way, we would also need to test existing knowledge sharing theories. This manipulation explains the experimental part of our case study, but because we did not strictly follow all the requirements for an experiment, the design is quasi-experimental. This is done to capture interesting emergent themes that we could not have foreseen. Thus, our qualitative research design lies somewhere in between a tight, pre-structured design and a loose, emergent one (Miles & Huberman, 1994).

Toward the pre-structured extreme, we had designed some categories within knowledge sharing literature, such as the visualization of information, tacit collaboration, and learning. Yet, it is important to recognize that a priori specifications of categories are tentative only, and that it is possible to shift from "theory-testing research into theory-building research by taking advantage of serendipitous findings" (Eisenhardt, 1989, p. 536). Furthermore, (Yin, 1994) states that "for case studies, theory development as a part of the design phase is essential, whether the ensuing case study's purpose is to develop or to test theory" (p. 27).

In this thesis, the case company was treated anonymously by referring to it as a general Chemical Co. As a result of anonymity, we have omitted specific details that can be considered as company secrets. Still, as our focus has been on knowledge sharing which is a general topic that happens in every organization. Thus, we believe anonymity has had minimal to no effect on our findings and our corresponding discussion. On the contrary, by ensuring the interviewees that their responses were treated anonymously, we believe they might have found it easier to share valuable information.

3.1.1 Case study

When selecting a case within Chemical Co., our main selection criterion was to find a department within Chemical Co. in which knowledge sharing was an important aspect of their work. Therefore, we relied on a theoretical sampling approach in our case selection and did not base it on statistical reasoning. Eisenhardt (1989) supports this by claiming that "the goal of theoretical sampling is to choose cases which are likely to replicate or extend the emergent theory" (p. 537). This led to the selection of the process systems engineering (PSE) group, as they were daily, weekly and monthly engaged in different kinds of remote assistance of knowledge sharing processes. Another, more technical, selection criterion was that AR remote assistance requires relatively good internet access and bandwidth. The remaining groups within Chemical Co. were few because they were mostly working in heavy concrete buildings which had weak WiFi and 4G signals. Thus, we decided to go for a single case study rather than a multiple case design.

In our research project, there is especially one rationale for choosing a single case over a multiple case design. This is when the single case can be regarded as a “critical case in testing a well-formulated theory” (Yin, 1994, p. 38). The remote assistance use case of AR represents a critical case of knowledge sharing because here people can collaborate and communicate via a shared view of the work as well as by visualizing their intentions and thoughts on top of the other person’s view of reality. We see this as a unique and critical case compared to the knowledge sharing activities which have been researched in knowledge sharing literature. This literature contains a vast array of extant, well-formulated theories with specific propositions that are believed to be true in a given context. Therefore, we will use this single use case to explore whether current knowledge sharing “theory’s propositions are correct or whether some alternative set of explanations might be more relevant” (Yin, 1994, p. 38). Thus, we believe that the single use case would give us the flexibility required to capture the complexity and depth of potentially interesting leads that may arise from the uniqueness of remote assistance with AR.

3.1.2 Literature review

In preparation for data collection, we conducted a literature review of cultural and analytical categories during the design phase of our case study. The literature review was done during the project report, Autumn 2017.

We started reviewing the literature regarding AR to understand its core values and capabilities. McCracken (1988) states that the literature review is of special importance in qualitative case studies due to its ability to sharpen the investigator’s capacity for a surprise as “the investigator who is well versed in the literature now has a set of expectations the data can defy” (p. 31). McCracken (1988) also adds that a “good literature review creates much more distance than it collapses" (p.31) . The selection criteria we used to find literature was: (1) the most relevant and up to date articles, (2) the credibility of authors and journals, (3) articles that integrated or overlapped with regards to the three core capabilities of AR.

First, we investigated the literature on AR from a social, historical and technological perspective. From this, we were able to identify the three core capabilities of AR as: (1) visualization and contextualization of explicit information (2) real-time collaboration while viewing the same operative field and (3) learning in an authentic and rich context. Out of these three core capabilities we considered knowledge sharing to be the general overarching and unifying theme between them. Thus, we decided to explore the knowledge sharing literature respectively through these perspectives. Through discussions with our supervisor and our contacts at the chemical production facility, we concluded that the second capability was of most value in this particular industry context because of its close connection to remote assistance. However, our literature review had not revealed any research integrating AR, remote assistance and knowledge sharing in the context we were interested in. Therefore, we decided to look to other industries for inspiration, and in particular the medical industry, as they have had a long history of applying remote assistance technologies as well as some AR technologies. Even though we had chosen the second capability as the main theoretical framework in which to analyze AR remote assistance we still decided to keep the other perspectives to triangulate with regards to different theoretical perspectives.

We did not only review analytical categories, but also cultural categories. According to McCracken (1988), there are three reasons for performing a cultural review: (1) preparation for questionnaire construction, (2) preparation for data-analysis by using 'self-as-instrument', and (3) understanding one's own perception of reality to establish a critical distance to it. First, we engaged in the process of familiarization and defamiliarization (McCracken, 1988). Here we examined our associations, incidents, assumptions, and biases concerning knowledge sharing, remote assistance and AR. This self-awareness analysis included using several techniques such as "introspection, inter-subjective reflection, mutual collaboration, social critique, and discursive deconstruction" (Finlay, 2002a, p. 212). This helped us to understand our role as interviewers, the relationship between the interviewer- and interviewee, and the research context to a much larger degree (Finlay, 2002b). According to

McCracken (1988), this process of familiarization and defamiliarization does not simply increase bias, but it gives a “clearer understanding of one’s vision of the world [which] permits a critical distance from it” (p. 33). As a result, we were more capable of spotting and creating distance in our respondents deeply embedded cultural assumptions (McCracken, 1988).

3.2 Data collection

To thoroughly understand the existing context, culture and knowledge sharing activities, we collected data both before and after the implementation of AR. This is in line with Patton’s (1999) statement that qualitative findings are by nature highly dependent on each context and case. Thus, before the implementation of AR, we interviewed seven process system engineers and observed four cases of remote assistance without AR. After the implementation of AR, we interviewed the same seven engineers and observed seven cases with AR. The selection of respondents was done according to McCracken’s (1988) principle of “less is more” stating that eight respondents will be more than sufficient for most research projects, because “it is more important to work longer, and with greater care, with few people than more superficially with many of them” (p. 17). In this way, we triangulated with regards to different data sources by comparing different perspectives on knowledge sharing of the seven different people within the PSE-group as recommended by (Yin, 2009).

3.2.1 Semi-structured interviews

The interviews were semi-structured and open-ended. As preparation for these interviews, we constructed an interview guide mostly based on the analytical categories we discovered in the literature review. By reviewing both our analytical and cultural categories, we were able to derive five overarching themes, respectively for the interview before and after the implementation of AR. In each and every one of these themes, we created non-directive and open-ended “grand-tour” questions (McCracken, 1988; Spradley, 1979). In this way we were able to ask unobtrusive questions without over-specifying the theme, springing our respondents to share their own experiences and perspectives (McCracken, 1988). To sustain the “grand-tour” questions we had prepared prompts helping the respondents expand on their utterances (McCracken, 1988). Additionally, we also allowed the participants to select and elaborate further on their own topic of preference. When some areas of interest within a particular theme did not emerge spontaneously during the interview we took a more proactive approach by using more obtrusive planned prompts like “category-” and “contrast” prompts prepared in our interview guide (McCracken, 1988). These interview guide are presented in Appendix A.

All the interviews were conducted during a week at the beginning of February 2018. The same seven process system engineers were interviewed before and after the implementation of AR. Each interview lasted from 25 minutes to 1 hour, and all of them were audio recorded. We informed all the respondents that the interviews would be anonymized. Thus, to preserve anonymity, aliases have been substituted in this study for all interview subject names. In table 2 below, we have presented an overview of the interviews conducted in our research.

Table 2: Overview of interviews.

		Before AR		**After AR**	
Interviewee	**Position**	**Duration**	**Number of transcribed words**	**Duration**	**Number of transcribed words**
Lars	System engineer (SE)	40	6305	30	4103
Jan	SE	45	6117	36	5317
Svein	SE	58	8298	26	3920
Joakim	SE	24	3436	25	3395
Gunnar	SE	38	5868	26	3906

Kjell	SE	40	6492	37	5236
Roar	SE manager	31	4666	19	2833

3.2.2 Participant observation

When doing participant observation, the investigator must increase his awareness and overcome years of selective inattention. Furthermore, the investigator must observe through a wide-angle lens to perceive tacit cultural rules, experiences as well as alternate between both the insider- and the outsider perspective. Lastly, the investigator must be introspective, and make good records (Spradley, 1979). As outsiders unfamiliar to the social context of the PSE-group, it was easier for us to perceive the governing tacit cultural rules (Spradley, 1979).

To not overlook the tacit cultural context, we were especially aware of the language being used while doing participant observation. According to Spradley (1979) it is “easy to overlook language differences and thereby lose important clues to cultural meaning” (p. 65). Thus, to avoid distortion of cultural meaning we distinguished between the native’s language and expressions, and our own. Furthermore, instead of creating an amalgamated language we split our field notes into two sections, one consisting of descriptive observations and partial verbatim records, and the other consisting of reflective content. In the first section we described the physical setting, social environment, participants, patterns- and frequency of interaction; and in the reflective section, we took notes on ideas, impressions, thoughts, criticisms, unanswered questions, concerns, misunderstandings, insights, and beliefs (LaBaree, 2009). This made it easier not to idly simplify or generalize. Instead, it aided in the process of perceiving and writing down the deeply embedded empirical details which are an integral part of “discovering the inner meaning of another culture” (Spradley, 1979, p. 67).

During our time as participant observers, Christensen, Hall, Dillon, and Duncan’s (2016) perspective on how to understand our ‘customers’ was very helpful. According to them, it is not enough to gather an enormous amount and variety of empirical data to understand the ‘customer’. However, what is more important is to identify the actual problems by addressing the anxieties and inertias the ‘customer’ may be feeling on their progress toward some goal (Christensen et al., 2016). Therefore, we were especially focused on observing these anxieties, pain points and compensating behavior in the participants.

We observed four cases without AR with a total of seven people. These cases were simulated issues of managing the manufacturing process. In the facility where the process systems engineers worked, there was a computer lab where the team could simulate different cases without affecting the actual production. Even though these cases were simulated, we made sure they were as realistic as possible. This was achieved by having a third party create a case on a topic which was not too familiar to the non-expert. Supporting the fact that these cases were realistic was that many of the engineers reported that they felt they received learning outcomes. The organization of the cases without AR is seen in table 3 below.

Table 3: Case groups without AR.

Case Group # without AR	Non-expert	Expert
1	Lars	Svein
2	Gunnar	Roar
3	Jan	Roar
4	Joakim	Kjell

Before proceeding with the cases with AR, we briefly presented the AR software during the morning meeting. Here we demonstrated the app by Scope AR called remote assistance where we showed and explained the different features and their functions. It should be noted that the process systems engineers were only briefly able to test the application before the cases. This was done because we wanted to test user-friendliness as well as whether or not the use of the visual communication features was self-evident.

The AR cases were done with the same pairs as shown in the table 3 above. We decided to use the same pairs because this would reduce noise, enabling us to more easily perceive the differences between the before and after implementation of AR, without having to consider differences in personalities and relationships as much. Out of practical reasons we decided not to go through with the case were Joakim would have been the expert and Kjell the non-expert, as Joakim had only been working there for two months and was being trained by Kjell. The organization of the cases with AR is seen in table 4 below.

Table 4: Organization of case group with AR.

Case Group # with AR	Non-expert	Expert
1	Lars	Svein
2	Svein	Lars
3	Gunnar	Roar
4	Roar	Gunnar
5	Jan	Roar
6	Roar	Jan
7	Joakim	Kjell

During these observations, we applied two different strategies of writing field notes. Wilfinger (2002) describes these as: (1) the salience hierarchy strategy, where one uses one's own tacit background knowledge to filter out what is most noteworthy and interesting; and (2) the comprehensive note-taking strategy. In both strategies, asking questions was of great value. Spradley (1979) states that all observations and perceptions are influenced by the questions in one's own mind, and therefore it is important to prepare descriptive questions. The first strategy is in line with Eisenhardt's (1989) statement that observational field notes should include a stream-of-consciousness commentary on everything that is happening. Thus, when we used this strategy we were always asking ourselves the questions "what am I learning?” and “what is unique about this case?”. In the second strategy, we used questions related to these general social dimensions: place, actor, activity, object, act, event, time, goal, and feeling (Roulston, 2017; Spradley, 1979; Wolfinger, 2002).

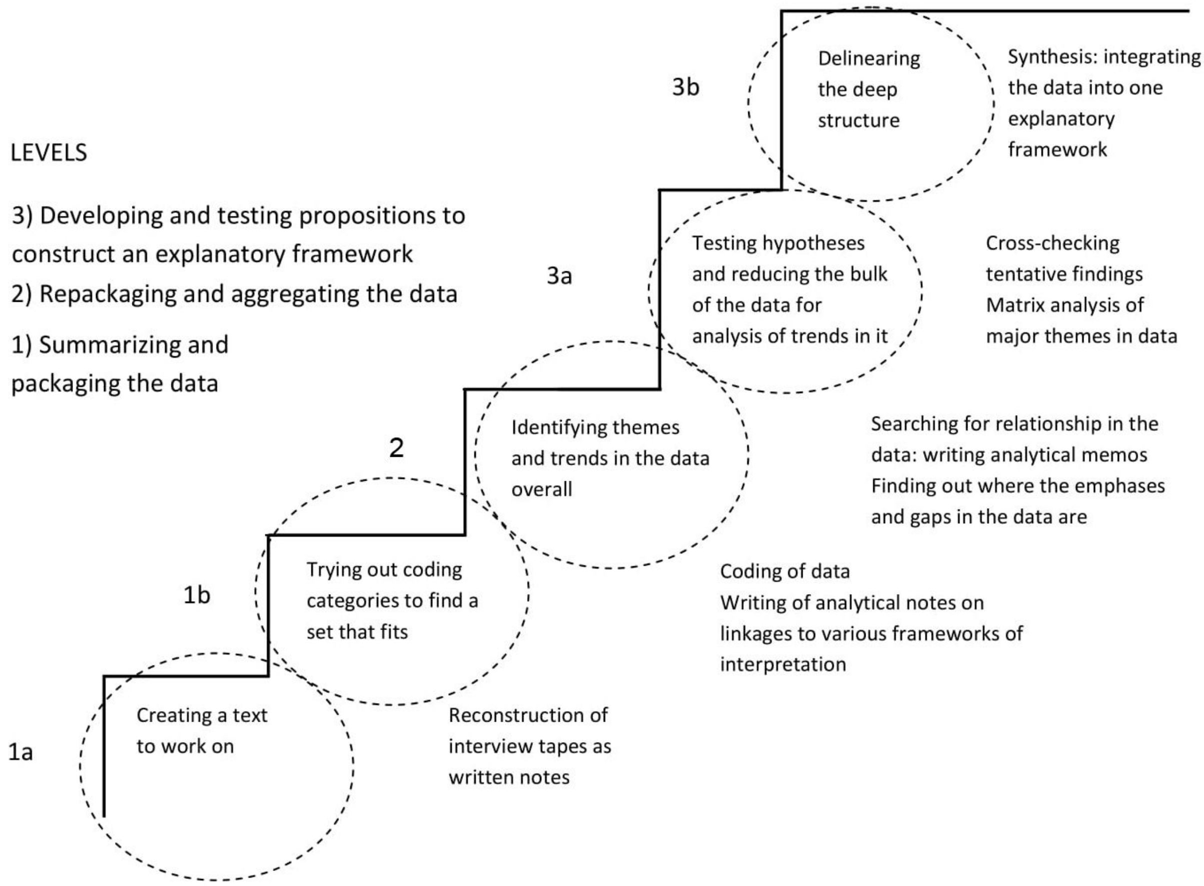
During the participant observations, we wrote in a condensed form. Later, often the same day, we spent a few hours trying to expand on these unconnected words and sentences. This is in line with Spradley’s (1979) statement that the “sooner you record your observations the more vivid and detailed your account” (p. 70). Additionally, when expanding on these observations, we also started the write-up process. The benefits of starting the write-up process early is substantiated by Wolcott’s (1990) claim that “writing is a great way to discover what we are thinking, as well as to discover gaps in our own thinking” (p. 21).

Based on the literature review and the use case analysis we concluded that an AR device with a head-mounted display combined with the remote assistance use case would be the most interesting to study. Thus, it was original desire to perform a case study with a head-mounted display in combination with the Scope AR’s remote assistance application called RemoteAR as this would sufficiently represent all AR features. However, due to financial constraints, we had to make do with iPad Pro 13 "(1st gen) as non-expert hardware, and an iPad Pro 10" (2nd gen) as expert hardware.

3.3 Data analysis and write-up

To analyze the data gathered by interviews and participant observations we primarily followed Carney’s (1990) ladder of analytical abstraction as presented by Miles and Huberman (1994), and McCracken’s (1988) 5 stages of analysis. Starting out with the interview and observation texts, we used different coding strategies and tried out different categories. Thereafter, second level patterns emerged to form more general themes. Lastly, these patterns, as well as hunches and analytical categories, were integrated into an explanatory framework to delineate the deep structure (Miles & Huberman, 1994). This process is presented in the figure 7.

Figure 7: The Ladder of Analytical Abstraction (Carney, 1990).



This process of constantly refining and winnowing down data is described by Wolcott (1990) to be the most crucial task of qualitative data analysis as the goal is to cover the essence in the data while still leaving sufficient context for understanding. Miles and Huberman (1994) supports this by saying that “data reduction is a form of analysis that sharpens, sorts, focuses, discards, and organizes data” (p. 11).

After the data collection process, we took the first step on the ladder of analytical abstraction (1a) by transcribing the recorded interviews and by further expanding our observational notes. According to Eisenhardt (1989), the overall idea of initial write-ups like transcriptions is to help the researcher “to cope early in the analysis process with the often enormous volume of data” and “to become intimately familiar with each case as a stand-alone entity” (p. 540). To achieve this level of familiarity with the data we transcribed the interviews we ourself had conducted so that we also got the chance to perceive the data from a more distanced perspective. These write-ups were central in laying the foundation for the later process of insight generation and insight emergence (Eisenhardt, 1989).

When doing first level coding in step 1b, we used the (Miles & Huberman, 1994) strategy of creating marginal and reflective remarks. While we were scanning through the interview transcription and observational field notes we were mindful of our own ideas and reactions and wrote them down as marginal remarks. As McCracken (1988) puts it, this is where we used ourselves as instruments by listening to the constant "stream of associations evoked by the stream of utterances" (p. 44). We focused our whole attention on each utterance and sentence, postponing our desires to generalize for later (Glaser & Strauss, 1967), and thus going "through the utterance into the assumptions and beliefs from which it springs" (McCracken, 1988, p. 44). Additionally, in a slightly more analytical frame of mind, we expanded these marginal remarks into reflective remarks by considering their implications and possibilities as well. According to (Miles & Huberman, 1994), both these remarks strengthen coding by "pointing to deeper or underlying issues that deserve analytic attention" (p. 66).

On step 2 of the ladder of analytical abstraction, we did one more iteration of analysis on our transcription and observational notes including the descriptive and reflective remarks. While first-level coding serves the purpose of summarizing data, second-level coding segments this data into more meaningful units of analysis such as patterns and themes (Miles & Huberman, 1994). Here we looked for "all logical relations, not only those of identity and similarity, but those of opposition and contradiction as well" (McCracken, 1988, p. 45). However, in this process of refinement, there is always a danger of falling prey to our assumption that we understand the nuances and meaning of the themes, and thereby thrusting new data onto these themes that may not fit adequately.

Therefore, we took several measurements to inhibit us from prematurely jumping to conclusions in the coding and theme identification processes. First, we decided to analyze each case couple's interview and observational notes together. For example, Roar and Jan were paired up in one case, and thus we analyzed the interview with Roar and the interview with Jan together with the case notes for their case cooperation. Second, to leverage our divergent investigator perspectives we did step 1 and 2 separately before comparing our results between us and moving onto step 3. Lastly, we decided to finish our analysis on all the cases without AR before we started analyzing the cases with AR to reduce bias between the cases. In this way, we were able to deepen our understanding of each case. The themes that had developed within each interview, went through yet another process of refinement in step 3 of the ladder of analytical abstractions. Finally, we were left with five themes that were integrated into our thesis. The themes that were integrated into our thesis can be seen in figure 6.

In the course of the analysis, we selected excerpts of conversation from the interviews that were particularly illustrative. The excerpts included in the empirical findings have been edited for clarity, and cleaned for hesitations, pauses, and redundancies, except where they carried meaning. We did this in line with Sætre (2003), who also stated that the inclusion of excerpts is important for several reasons:

> First, we are dealing with rich qualitative data, and the excerpts are a way of transferring or communicating that richness to the reader. Second, much of the data is often mundane in relation to the topic at hand. Since verbal communication is much more varied and unstructured than written communication, every effort has been made with regard to the transcription, selection, and translation of these excerpts to make meaning as clear and uncluttered as possible so as to enrich the reading experience (p. 75).

Furthermore, comments irrelevant to the topic at hand were removed and denoted with leader dots, but only where one could be confident that the meaning was not altered.

3.4 Quality of research

Research quality can be established and assessed through construct validity, internal validity, external validity, and reliability (Yin, 2009).

3.4.1 Validity

Construct validity refers to "identifying correct operational measures for the concepts being studied" (Yin, 2009, p. 40). To ensure construct validity we have established a chain of evidence, developed a distance to analytical and cultural categories, and used different triangulation sources. First, in line with Yin (2009), we have documented the different processes during data collection and analysis, and believe that this will be sufficient for external researchers to follow all the steps we have taken. Second, during the interviews there were many concepts we believed would be subject to ambiguity such as tacit knowledge sharing. Instead of spending effort on trying to explicitly establish a common understanding of the different concepts and having the risk of creating biases, we followed McCracken's (1988) approach of using the concepts that our interviewees themselves used. Thus, we focused on establishing and creating distance to the analytical and cultural categories in both ourselves and our participants. Third, methodology triangulation was achieved by performing participant observation as well as semi-structured interviews. These methods were chosen based on the fact that they complement each other's strengths and weaknesses (Carney, 1990; Miles & Huberman, 1994). Further, investigator triangulation was achieved by leveraging our divergent research perspectives through for instance conducting the interviews in two-person teams in line with Eisenhardt's (1989) interview strategy. Here, the person who handled the interview questions could engage in more personal and direct interaction, whereas the other person could observe, take notes, and reflect on the broader overarching patterns and themes of the interview. By delegating roles like this, the interviewer could more easily immerse himself in the details of the case study and follow up on hunches, knowing that if he forgot the structure of the interview, the observer would pull him out and take him back on the right course. When we perceived a situation differently we tried to reconcile those differences, because "divergence can often turn out to be an opportunity for enriching the explanation" (Jick, 1979, p. 607). Patton (1999) also supports this by stating that the "finding [of] such inconsistencies ought not be viewed as weakening the credibility of results, but rather as offering opportunities for deeper insight into the relationship between inquiry approach and the phenomenon under study" (p. 661). Triangulation helped to corroborate our findings, and thus increased construct validity (Yin, 2009).

Internal validity seeks to "establish a causal relationship, whereby certain conditions are believed to lead to other conditions, as distinguished from spurious relationships" (Yin, 2009, p. 40). As our study is of an exploratory kind where we have not sought to establish causal relationships, but instead formulate propositions and hypotheses, internal validity is deemed not to be relevant (Yin, 2009).

External validity defines the "domain to which a study's findings can be generalized" (Yin, 2009, p. 40). To make our findings apply to other departments and industries, we made generalizations based on three different dimensions: complexity, severity, and frequency. By defining the scope and boundaries of these dimension on a scale from low to high, we increased external validity (McGrath & Brinberg, 1983). On the other hand, more intricate nuances of knowledge sharing related to for instance the influences of context and culture may lie outside of the boundary of this generalization. Thus, our findings may be limited to the context and culture presented in our empirical data. Furthermore, our findings have not been replicated and thus our generalizations are not automatic (Yin, 2009). To make up for this, we made effort to fully describe the characteristics, culture, and context of our research sample to enable other researchers to compare and assess the transferability to their own sample and context (Miles & Huberman, 1994).

3.4.2 Reliability

Reliability demonstrates "that the operations of a study - such as the data collection procedures - can be repeated, with the same results" (Yin, 2009, p. 40). First, measures were taken to minimize subjective biases and errors in the study by always being two investigators. Second, reliability in qualitative research can be increased through documenting the iterative process of reflection and analysis (Kirk & Miller, 1986). Thus, we have increased the reliability of our case study by creating a database which contains the interview guide, audio recordings, transcripts, field notes, and first, - and second level coding with marginal and reflective remarks. On the other hand, our flexible and opportunistic research approach may affect reliability in a negative way. This is because the semi-structured and open-ended nature of our research approach may make it more difficult for other researchers to replicate our interviews down to minute details. Still, we expect that by following the interview guide with the general themes, grand-tour questions and prompts, any researcher would be able to replicate our research procedures and produce the same results.

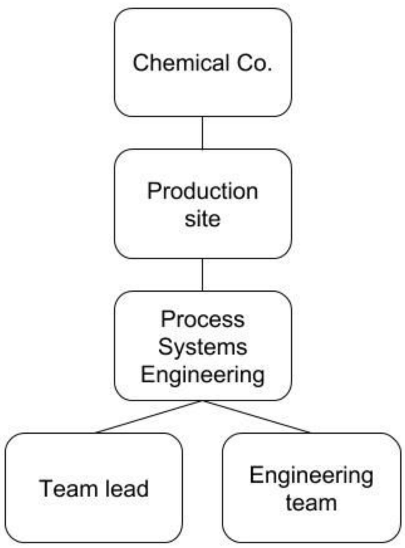
4 EMPIRICAL FINDINGS

In this chapter, we present the empirical findings from the interviews as well as the observations of the cases with and without AR.

4.1 Introducing the need for remote assistance in Chemical Co.

Chemical Co. is a large chemical company headquartered out of Norway with over 14 000 employees competing in the global market with production sites all over the world. The team under study is part of one of Chemical Co's largest production sites located in Norway with roughly 450 employees. The team works in a technical department dealing with process systems engineering of the chemical production facilities. In this team, there are seven process systems engineers where one of them is the team leader. Below is a high-level organizational chart illustrating where the team resides in the company.

Figure 8: Organizational chart.



Industrial production of chemicals is a complicated process and requires many computer systems. To maximize the production of the chemicals, which is required to maximize profits, these computer systems must run continuously and without faults. Therefore, maintenance and support of these systems is a primary task of the PSE-group. In addition to maintenance, improving upon existing systems is also needed to stay competitive in a global market. Thus, Lars describes the work being done by the team as being two-fold:

> I work in a team in technical support which consists of 7-8 people with control systems, safety systems, PLC's [Programmable logic controllers] and it is two-folded actually. We do projects and we do support and maintenance of the systems that we already have. So, everything is control- and safety systems, and process related of course.

As many of the systems maintained by the PSE-group run continuously as part of the production process, the team must be available at any given time to provide support should there be any issues related to their systems. The team has therefore put in place a duty system, which they rotate on once a week. One of the challenges that the engineers meet when being on duty, is that they must support all the systems that the group as a whole has responsibility for. As Lars puts it:

> While on duty we have to support everything, and that is a challenge for us. Some things you know really well, some things you know fairly well, and other things you do not know that well. It is very diverse. You can be called on to resolve a problem on a system you do not know that well.

Knowing everything is impossible for any employee working in Chemical Co., be it an operator, engineer or manager. Thus, knowledge sharing is an important activity to keep the production of chemicals continuously running at maximum capacity. Given that all the employees of Chemical Co. cannot be available at the same place, at the same time at all times, the need for sharing knowledge remotely becomes evident. To better understand knowledge sharing with remote assistance in Chemical Co., we will describe the context in which this knowledge sharing happens. The context is split into three parts: the people who share knowledge, the environment in which they share knowledge, and finally how they share knowledge.

4.1.1 The people who share knowledge

The PSE-group consists of people who are highly committed to their jobs. A large contributor to their commitment comes from their interest in the field they are working in, which is technology:

> There is a lot of commitment here [in this group]. There are many here who have found their right place in terms of interests and therefore, they give a lot to Chemical Co., and in that way, they bring something more of themselves with them to work, they really do (Roar).

Furthermore, the group spans the age spectrum well with people in their early 30s to their mid-60s. Both the young and the old share an interest for technology and their field: “We share a lot of interests, we are allowed to be a very technical environment, one of the few places in Norway where we can be in a group like this” (Roar). To support such a technological environment, Gunnar noted that the managers regularly introduce new technologies into the department: “the leaders here are very good at getting new things. They are very proactive, we get to go to trade fairs and user seminars to look at new things.” Furthermore, Chemical Co. is a company willing to invest in new technologies. The company is a technologically driven company from the top level. Joakim, the newest engineer to join the team notes that Chemical Co is: “very progressive down here, very ready to try new things and very willing to invest” (Joakim). He goes on to note that Chemical Co. dares to bet on new technologies, instead of always being behind. To a group of engineers with an interest in technology, this is very exciting and it fuels the engineers’ commitment to their jobs. Instead of waiting to replace components until something stops working, the company has a strategy to improve current systems continuously. This helps reduce the company’s technical debt, which can easily accumulate if not dealt with. Technical debt introduces the possibility of having to completely overhaul larger sets of systems at a later time, which may take more effort in total compared to keeping systems up to date. This is why the PSE-group spends a significant amount of their time on projects aimed at improving or replacing current systems with better ones. This also keeps the team continuously learning, as opposed to simply just maintaining a set of systems that do not change.

Apart from sharing interests, the engineers in the team are very competent employees. The team leader noted that he does not need to micromanage his team: “in my job there, is a lot of coordination, planning and making sure we have people, but I have very competent people, which means I do not have to micromanage” (Roar). According to Jan, the engineers in the team are their own bosses:

> Here with us, it is more that I know, or should know at least, what needs to be done and what does not, and have control over it myself. There is no one who really controls, could almost say we are our own bosses.

With such autonomy also comes responsibility and with responsibility comes pride in their work: “it [being available at any time] is probably somewhat related to professional pride, we want the solutions we set up and maintain to be as good as possible” (Kjell). These are highly educated engineers who maintain operation critical systems. Their main goal is to keep the systems running at all times.

Important for the knowledge sharing process is that the engineers in the PSE-group know each other well. They are a rather small and cohesive group which works together on a daily basis. Furthermore, they eat their lunch together daily which gives them time to socialize. Most of them have worked in the same group for several years. Having worked together for longer periods of time, the team has been able to develop trust between each other as team members. Kjell compared the remote assistance situation in the context of the PSE-group to the job of defusing a bomb and calling for expert help: “It is very OK if it is a person you have worked closely with for five years. You have done many of these operations together, you know you can trust him” (Kjell). Knowing each other well also simplifies communication, as the team shares a common language: “We have a common language, common expressions. So, it is fairly easy to be the expert, when the non-expert is as competent as we are in this group" (Lars). Furthermore, the engineers also know what the other team members know. This is important, as it allows the engineers to give more personalized assistance in a remote assistance situation between two engineers in the PSE-group: "We know what the others work with and what they know … I know who to ask, usually it is one or two persons I ask in regard to this or that system" (Kjell). This is especially the case when it comes to the larger systems. However, Lars mentioned that they do not always know who has been involved in every project. For example, if a project was put into operation the day before, they do not always know who performed that particular job.

The reason the team mostly knows who knows what is because the responsibility for the different systems has been divided among the team members. As the group supports many different systems, no single person can know all the systems. Therefore, each team member has his system or systems that he has responsibility for. Moreover, the biggest systems have an additional expert. This way, if the main expert cannot be reached, there is a second expert that can be contacted. Consequently, the team works towards knowledge sharing by not having any single engineer be the only person with expert knowledge on any given system. Still, when an engineer is on duty, he must support all the systems maintained by the PSE-group. Therefore, the team is entirely dependent on sharing knowledge.

Culture

As a team dependent on sharing knowledge, they are not at all afraid to do so. Knowledge sharing is a very regular thing in the PSE-group: "we are quite open and quite honest, we really try to do each other well … If we have a challenge then we talk about it here, we almost never say that one should have known" (Gunnar). Knowledge sharing has become part of the culture in the PSE-group. As noted by the newest engineer to join the group, Joakim: "here, everyone is very, they share the knowledge they have, and obviously that is the way it should be". In addition to helping each other, being open and honest, several engineers point out the fact that they are able to talk about almost anything, and they are not afraid to do so either. In addition to being able to discuss almost anything, the engineers also actively challenge each other. The team leader, Roar notes how the team discusses issues:

> I feel we are factual in the discussions, we discuss the issues, and in that way we, challenge each other a lot in terms of pushing each other. For example, if someone says "no, that one needs more comments", we do not filter, we trust each other that much.

The reason they do this is because they all share the same goal of maintaining the best possible systems with the lowest amount of downtime. To reach this goal, it is in everyone's interest that they keep improving their systems by challenging each other if necessary. When they challenge each other, they also learn from each other. Gunnar notes how being open to learn from others is important, as there is always someone who is better than you, therefore he emphasizes that listening is an important skill, and one that they possess in the PSE-group.

A culture that embraces knowledge sharing is self-reinforcing. As noted by Kjell: "if you help each other then the unity of the group increases." This coincides with the fact that the group feels a high sense of unity, as they all must support all the systems the group maintains when they are on duty. One engineer noted how he has never experienced anyone not willing to solve a problem. Another engineer noted how the team can call each other at any time:

> And if a problem occurs, you can just call each other whenever and wherever, we will answer anyway. And then I will get the help I need … so us in the on-call duty, we have to, we are dependent on each other. We are only human. (Gunnar)

Jan noted how he has been called on late at night, which he does not consider a problem, because he knows that the next time he needs help at an inconvenient time, he is also able to request it. Furthermore, Jan noted how the team does not have any written rules for remote assistance: "there isn't even any discussion about it, if it is okay or not, it is just the way it is … a norm." Moreover, he goes on to note that the environment for collaboration is not very ambiguous. Jan noted that this makes the culture easy to navigate. This coincides with the culture the team has for openness and trust in terms of discussing issues. In summary, the PSE-group has a culture that embraces knowledge sharing through openness in discussions, trust, unity towards their shared goal and a willingness to help each other in any situation where one actor might be more knowledgeable than the other.

4.1.2 The environment where knowledge sharing happens

The PSE-group works in a high-risk environment where one mistake can lead to severe economic damages as well as hazards towards other employees working more closely with the chemical production machinery. One of the engineers noted that it can be stressful: "obviously it can be stressful because you know that there is a lot at stake" (Lars). Furthermore, Gunnar noted that in their job, they have zero room for errors. The reason why the engineers have zero room for errors is because they develop and maintain operation critical systems where a single mistake can result in safety hazards and severe economic damages for the company.

The systems

The systems that the team has responsibility for are intricate and complex computer systems that are built by a lot of logic. Furthermore, few of the systems work independently. Therefore, most of the systems are dependent on other systems. This means that when a change is made in one place, the effect might spread to many other places:

> It is a control system set in a system with a network consisting of operator stations, configuration stations, controllers and I/O cards. So, there is potentially a lot of reasons why it [the production] stops, in a sequence or a logic, or some other control structure (Lars).

One of the other engineers who has worked in Chemical Co. for a significant amount of time uses the nervous system as an analogy for the type of systems the PSE-group works with:

> We work with the nervous systems right, if you understand the systems then it is just a few small threads that we work on, So, making an adjustment is simple, you might invert a signal and then bang, it [the production] stops …

> You need to know exactly what you are doing, we cannot afford to make mistakes (Gunnar).

As the team supports many different systems, no single engineer can be the expert on all the systems. Therefore, each team member in the team is an expert on a particular system: “we have our areas where we are specialists” (Lars). However, even if an engineer is an expert on a given system, he cannot know everything about the system. As Svein expresses it: “If you are an expert in one field then you are supposed to be, well, you are the expert, you are supposed to know everything, but nobody can know everything.” Furthermore, knowing one system does not necessarily make it easy to understand another system. Still, there are several systems that perform similar tasks. In these systems, some things are named differently, but they perform the same function. Another factor working against the engineers is the fact that the systems keep getting updated or replaced through various projects. This means that the engineers must constantly learn as nothing stands still.

With such complex systems that are affected by a plethora of variables, writing down manuals with the goal of substituting the expert help provided by the PSE-group is not considered to be an effective way to share knowledge: “It is too complex ... a manual, it would not be possible … because then you assume the same conditions, here things get older, things get worn out, the weather changes, everything is affected right” (Jan). In summary, the PSE-group works with highly intricate and complex systems that are critical for the continuous manufacturing of chemicals.

4.1.3 How knowledge sharing happens now

As the knowledge to solve problems that arise cannot be written down efficiently, there is a need for expert help from the PSE-group. Furthermore, as no single engineer can know everything, or be available at any time, the engineers rotate on the on-call duty responsibility. On duty, an engineer must support all the systems maintained by the PSE-group. To support this function, the team has duty training once a month: “the person who has responsibility or competence on a given system [holds the training] … then we have a half day of training where we go through equipment, where the equipment is, simple troubleshooting” (Lars). On each duty training, the team gets training in a different system. The duty training is not enough to be able to fully support the given system, but it helps the engineers associate a person with each system by considering who holds the training session. Furthermore, just knowing where the equipment for a system is located is helpful: “I do not know how many computers and servers we have, it has to be in the hundreds. There is no one who knows exactly where everything is, just that can be a challenge, finding the equipment” (Lars). In addition to the monthly duty training sessions, the team has morning meetings on Mondays and Thursdays where the team shares knowledge and discusses “anything that has come up recently, and we can discuss who needs to handle it” (Jan). Apart from the knowledge sharing activities which are set, the team also shares knowledge on an ad hoc basis. For example, if two engineers start discussing something in the hallway, they might take it to a meeting room and include more of the team. In other words, they share knowledge when they can, as they know that combining knowledge often results in new knowledge. The engineers also have an incentive to know as much as possible, as they must support all the systems the team maintains when on duty.

When an engineer gets called upon, he will attempt to give support to the best of his ability. The person on the other end varies. For the most part, it is the engineers who call each other: “mostly we call each other, but it might happen that an operator calls directly to one who is not [on duty], usually they call the engineer on duty” (Jan). An operator works in the operations department. The operations department monitors the production of chemicals and should there be issues that they are not able to resolve themselves, they might contact the PSE-group: “And then they call us right, and very often it is related to operational support. It is not usually a breakdown of our equipment, but still, it is usually the control systems that are seen as the constraints” (Lars). Other than the operations department, there is also a group of electricians on duty that frequently contacts the PSE-group: “they also have electricians on duty that are here to take things that come up outside of working hours on more electrical systems and more field-like things” (Lars). When called upon to resolve a problem, an engineer considers three important factors.

The severity of the situation, the level of expertise of the person calling, and finally the engineers own level of expertise in relation to the problem at hand are factors considered when the engineers are called upon. The reason these factors are considered is because the engineer who gets called upon must make a decision on whether he should attempt to remotely assist in solving the problem, if he needs to physically be present on site to get as close to the problem as possible, or if he needs to further request remote assistance from a more knowledgeable person on the given problem.

The severity of the situation depends on several factors, where the economic damages of constrained production, as well as employee safety, are the most important factors for Chemical Co. As Roar puts it: “if the ammonia production stops, that is roughly one million euros right there” (Roar). The production of ammonia is a critical part of the production, and should it come to a complete stop, bringing it back to full production capacity requires a certain length of time. As Chemical Co. aims to maximize output, minimizing plant downtime is therefore desired. Thus, the longer the production is at a halt, the higher the economic damages will be. However, there are situations in which problems do not completely halt production, but rather constrains it. In this case, when the production is not very constrained, the severity can be considered not to be very severe: “even if the whole factory does not stand still, but maybe the production is a little constrained, you can choose to let it be until the next day” (Jan). In addition to minimizing economic damages, Chemical Co. also aims to minimize injuries at work.

The production of chemicals requires several chemical components, chemical reactions, and machines with moving mechanical parts. Most importantly, the production requires people. While automation has relieved people from many hazardous tasks, the production is not yet fully automated. Thus, people are still required to be on site for various tasks that need to be performed manually. If a problem with the production should occur while employees are present, this poses safety risks: “if you bridge [to put in manual] wrong then the tanks start running over and then. Well, hazards towards people, we do not want that either” (Roar). As Chemical Co. has an ambition to reach zero injuries in their manufacturing process, safety is a critical factor when an engineer considers the severity of a situation. As Kjell puts it: “whatever people do here, they will be involved in safety work”. If the safety of employees is threatened, the severity of the situation is regarded as critical and a solution must be found by any means necessary.

In parallel with understanding the severity of the situation, the engineer will try to understand the level of expertise of the caller. If the non-expert does not have a sufficient level of expertise in order to be able to describe the situation, then it will affect whether or not the engineer decides that remote assistance is applicable in the given situation. The same yields if the non-expert is not able to understand the expert's guidance: "it happens every so often that you [the expert] are not understood, and at that point, the only option is to travel down there" (Svein). Not being understood is something an engineer understands through the conversation: "You can easily hear it if you are not getting anywhere. But it also depends on what was wrong in the first place" (Svein). Having to approach the problem by traveling to its location can be costly for the company and inconvenient for an engineer who might be at home in the weekend. Thus, being able to solve the problem through remote assistance is preferred.

Lastly, the engineer must also determine his own level of expertise in regard to the given problem. If the engineer finds that it would be more efficient to contact another engineer with more expertise on the given problem, then based on the severity of the situation he might choose to do so. In summary, the PSE-group shares knowledge both in organized manners through activities such as duty training, as well as in ad hoc ways, such as when support needs to be given to solve a problem remotely.

4.2 Remote assistance without AR

When the team performs remote assistance, they use mobile phones as their primary technological tool. This constrains the two persons in a remote assistance scenario to oral communication. However, the team has experimented with using the camera function of their smartphones with applications such as FaceTime.

4.2.1 Competency level

In remote assistance scenarios with current tools, knowledge sharing is affected by both the competency level of the sender and receiver of knowledge. If the sender and receiver have a similar competency level, then it is easier for the two persons to be precise in their explanations of the situation: "the advantage with Lars is that we work on the same control system. Therefore, it is easier for him to be precise with me, should he need to guide me and vice versa" (Jan). While the competency level can be similar between two of the engineers within the PSE-group calling each other, the competency level can vary a lot outside of the PSE-group. In regard to the source of competence, Lars noted that it is primarily experience. However, education also plays an important factor: "it is first and foremost experience, however, we are obviously here because we have a given education, so it is clear that it is connected to that" (Lars). While the experts in the PSE-group have engineering degrees, the competency level outside the PSE-group can vary.

Outside of the PSE-group, the operators and the electricians who request remote assistance from the PSE-group usually only have a certificate of apprenticeship: "they have a certificate of apprenticeship in process or in logistics, mostly in logistics, but I would not say it is a higher education" (Svein). Thus, the competency level of these non-experts can vary significantly. As noted by Lars, some have barely worked with computers:

> There is a very large difference in competency level there. Some have barely worked with computers and control systems. To explain to someone completely fresh how to log into a windows station, and into a specific application, and in that application troubleshoot a specific component. It is not always that easy, without having anything visual.

The engineers noted that it can be very challenging to remotely share knowledge on a system the non-expert has very little previous knowledge on. Thus, knowing who is on the other end and their competency level is emphasized as an important aspect of the job to provide remote assistance. One of the more senior engineers emphasizes that he has been there for many years, which means that he knows people and consequently knows their competency level. In other words, there is a clear connection between knowing people, and knowing their competency level in regard to knowing how much knowledge an engineer is able to share in a remote assistance situation.

At the same time, the type of questions asked by the operators and electricians are usually simple. However, when the caller is another engineer in the PSE-group, the problem is often more complex as the engineer on the other end has most likely attempted many of the solutions which would normally be told to the operators or electricians. In other words, the lower the competency level of the caller, the more likely that it is a fairly simple problem, while the higher the competency level, the more complex the problems are. Another factor that the engineers consider when asserting the competency level of the caller in a remote assistance situation is whether proceeding can be harmful:

> You notice it after a few questions whether there is any point in trying to provide support over the phone, can we get to our goal, or is it actually more dangerous to proceed, because it might be that the completely wrong action is performed (Roar).

As the risk of making a mistake can have severe economic damages, let alone safety hazards towards the employees on site, this risk must be minimized. Thus, if the engineer suspects that the caller does not have the competency level to absorb the given knowledge and is at risk of making a mistake, the remote assistance situation will be aborted. Thereafter, the engineer will have to further consider the severity of the situation to decide whether he has to physically approach the situation to solve the problem himself. In summary, competency level has been found to affect knowledge sharing significantly and especially the difference in the competency level of the expert and the non-expert has been found to be an important factor when sharing knowledge.

4.2.2 Mental model

When sharing knowledge through remote assistance, the mental models of both the expert and the non-expert play an important role. The situation requires the non-expert to construct a mental model of the problem before conveying it orally through a mobile phone to the expert. The expert then must deconstruct this mental model to understand it, then he has to construct his own mental model of the situation and convey it back to the non-expert. The non-expert then has to understand this mental model and finally perform an action based on it. The engineers find this to be challenging with only oral communication to convey mental models:

> It is challenging because you must try to explain, remember the screenshots, remember the menus, and with only a mobile phone, go up to the left corner, click on file, go down, did you find it? Where was it, in what menu was it again. Then you ask them to go through the menus … with a mobile phone, you must be very systematic when troubleshooting (Svein)

As the PSE-group provides support mainly for computer systems, having a mental model of a computer program in their head is a challenging task. It requires a lot of memorization, as there are usually many steps in a program to perform a specific task. Especially in a troubleshooting scenario, which is what the engineers most commonly find themselves doing remotely when they need to share their knowledge. Furthermore, and without visuals, there is a lot of uncertainty between the two actors in the remote assistance situation. For example, the expert cannot be sure that the mental model conveyed and understood by the non-expert is, in fact, a correct model of the actual problem:

> To explain which interface, which image you are in, and a control system which has many images, and then you think to yourself that the other person knows that you are on that image, but it might not be so easy to understand (Joakim).

The consequence of this is a mismatch in mental models. This goes both ways, as Jan puts it: "it is not always that the images one remembers and tries to convey are the right ones, you would have easily understood it had you been there physically." This is even harder for the expert if he has not encountered the exact problem before: "it might be a situation you have not seen before, and then based on your knowledge you have to try to give guidance" (Jan). Not being able to be there physically, Jan noted that having something visual to minimize the uncertainty of a mismatch between mental models would have been useful. Furthermore, it would also help towards triggering memory by association, as having a complete mental model of a system is impossible. To summarize, the engineers find that understanding the mental model conveyed by the non-expert, as well as conveying their own mental model is a challenging task to perform using only a mobile phone.

4.2.3 Communication

Communication is highlighted by the engineers in the PSE-group as an important factor in regard to knowledge sharing in remote assistance scenarios. Furthermore, one of the engineers noted that communicating in person is the most effective way of communicating: “you can sit in conferences and hold many meetings and such, but there is something about being in the same room, which is probably the very best” (Kjell). He goes on to note that if the two people involved in a remote assistance situation have never met, then meeting in person before attempting to work together remotely can be beneficial:

> I think it has something to do with trust, that you get an impression of the person who is going to explain something to you, if you should click this or that button. I mean, will we get a slip up now, and then the factory stops (Kjell).

The employees in Chemical Co. work in a high-risk environment where making a mistake can lead to severe consequences. Thus, trust is highlighted as an important factor when communicating remotely. Another factor that is highlighted is to what degree the two participants in the remote assistance scenario share a common language: “in a way we have one tribal language towards the field and a different tribal language towards system … we use a larger vocabulary of the tribal language when I speak with my boys than with the electricians” (Roar). Gunnar noted that it is very important to speak the same language to understand each other. He goes on to mention that there are different cultures in Chemical Co., and this influences the language spoken: “there are different cultures around an operator and us, we speak a little different of the same thing, the names of things might be a bit different” (Gunnar). Speaking differently of the same thing can lead to miscommunication and misunderstandings.

To reduce the probability of misunderstandings, several of the engineers noted that they have to be very precise when communicating over the phone: "it is very important to be precise and to ask control questions to make sure that the other person understands" (Joakim). In order to be precise, having a common language helps:

> The advantage with Lars is that we work on the same control system. Therefore, it is easier for him to be precise with me if he should need to help me or vice versa. It is easier for him to be precise in the description of the problem (Jan).

Precision is something required of both parts in the remote assistance situation. The risk of being imprecise is the loss of valuable information crucial to either define the problem to the expert or define the solution to the non-expert: "and when he does not see it, and he who sits in front of the screen does not say it, you can lose important information when using only a mobile phone" (Kjell). Kjell goes on to emphasize that having visuals would reduce the need to be as precise in communicating. Having visuals as an aid to communication is also mentioned by Lars as being useful: "maybe you saw that we conveyed [information] via a screenshot on iPhone ... Take a picture of a sequence right, that shows the status then and there, so we can bring it and discuss it the day after" (Lars). To summarize, communication constrained by a mobile phone in a remote assistance scenario can be challenging due to the risk of misunderstandings, a different language, and imprecision in speech.

4.2.4 Learning

In an environment with a set of knowledge-intensive and continuously changing systems which the PSE-group develops and maintains, continuous learning is an important skill to possess. Especially to be able to absorb and share knowledge in remote assistance scenarios. Kjell noted that the engineers in the team consider this to be positive:

> It's not like you can rest on your laurels, it's not like if you've learned a system then it's fine, we have control over that. But that's good for us, we like

> to have something to do, it would have been boring if we had to work on the same thing all the time (Kjell).

As the PSE-group constantly keep developing their systems, everyone in the team has to continuously learn from each other to stay as much up to date as possible. Furthermore, as everyone in the team has to learn from each other, learning is just as much about teaching as it is about learning. Gunnar, the most senior engineer in the team noted that teaching can be just as valuable as learning: “you learn more from teaching than being taught because then you have to put words on it” (Gunnar). He goes on to note that teaching is “the best thing you can do because then you have to understand the material better yourself” (Gunnar). While teaching is naturally the other part of learning in a knowledge sharing process, Gunnar emphasized that teaching has the added benefit of learning as well.

One of the challenges that the engineers in the PSE-group have is trying to understand as much about all the systems that they maintain and support as a group. The sheer amount of knowledge needed to maintain and support all the systems under the responsibility of the PSE-group is large, and no single engineer can have as much knowledge as the whole group is able to hold at once. Therefore, the group requests remote assistance from each other when faced with a problem they cannot solve themselves. However, knowledge shared in a remote assistance scenario is not always retained:

> Even if you get a refresh on the knowledge right there and then because you are communicating remotely with someone who works with it [the system] every day … but it might be forgotten after two weeks, so even if the same problem occurs the next time, you’ll still get a phone call (Jan).

One of the reasons knowledge does not get retained after it has been transferred and applied in a remote assistance scenario is because the non-expert who requests the knowledge is often constrained by time. Furthermore, the non-expert has a need for knowledge in the situation where it is needed, but once the problem is solved, the non-expert will move on to the next problem:

> Often, it is about fixing a problem then and there. And then afterward it might be put aside, you might not evaluate and try to learn … it is often putting out a fire … there are four people waiting to get things done, and then you get it done, and then you're happy (Joakim).

Another reason why knowledge does not get retained after a remote assistance scenario is that the systems are complex, and a single instance of a given problem on a given system is not enough to fully learn from the situation. With such complex systems, they require practice. Furthermore, with such diversity in the problems that can occur, it is easy to forget when the same problem does not occur for an extended period: "that's how it is with human nature right, you have to practice regularly to become good, and if there is too much time between each time [the same problem occurs] then you forget" (Lars). To summarize, the PSE-group has to learn continuously, however, retaining the knowledge learned after a remote assistance scenario without AR is a challenge for the team.

4.2.5 Technological aspects

To address the limitations of a mobile phone call constrained to only oral communication, a few of the team members in the PSE-group has experimented with using FaceTime on their iPhones. FaceTime is an application which allows streaming of video and audio between two iPhones. Jan noted that the need to use this application has come from a difficulty in describing in every detail how an image on a screen looks like:

> It can be difficult for he who sits at home, to describe in detail how an image looks like, where you must click … then I have tried FaceTime when I have been at home and have needed to help someone on the control system that I work on.

The biggest issue with using this application has been that the video quality has been unreliable and poor. The reason that the video quality has been poor is likely because of the connection not being good enough. Streaming of video requires significantly more bandwidth than streaming of audio. Furthermore, in a remote assistance scenario the non-expert can be located inside the production facilities where the coverage is limited:

> I haven't used it many times … I think the video quality has been too poor when I have used it, some delay with speech … it is in an area with poor coverage as well, you might be in a steel construction, or a concrete building, and the configuration room, they are often in the middle of the plant, there's also technical equipment all around them, a little bad coverage sometimes (Svein).

While Svein was not impressed by the performance of FaceTime, it "worked there and then, we received help and he was able to guide us" (Svein). Thus, even though the application has limitations, it still holds some value. Another issue noted by Jan from an expert's point of view is how the screen on an iPhone feels too small to be able to notice all the details in the view the non-expert is presenting. Furthermore, from the non-expert's perspective, there are a lot of things happening at the same time: "he who is out there has to try to both film, use a mouse and keyboard, and talk with me" (Jan). Additionally, the non-expert also has to consider what the expert sees and adjust the view accordingly. Furthermore, even a small adjustment while holding the iPhone can result in losing focus of the important information that needs to be conveyed to the expert. As a result, there is no shortage in things that need to be considered at the same time for the non-expert.

In regard to remote assistance on computers, there exists native computer applications with a screen sharing function. One of the most well-known applications for this is called TeamViewer: "If I had that [teamviewer], could of just put that in, then it would have solved all of my problems" (Jan). Svein, one of the other engineers also expressed how using an external device to film a computer screen seems odd when there exist native applications to remotely share computer screens. The reason that the engineers do not use such applications is due to safety and security. The team does not want to make it possible to control any of the systems remotely, as this would pose a severe security risk.

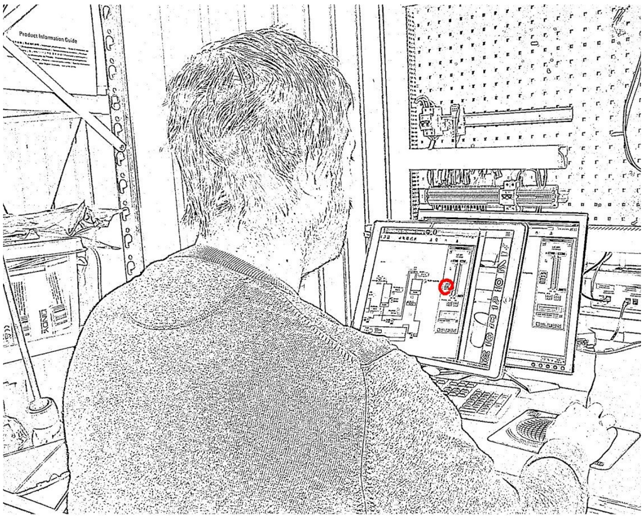
A technology with a significantly lower risk is a mobile phone which is a mature technology that has been proven to work. Furthermore, it is portable, and it is quick to set up a call. In the remote assistance situations that the PSE-group often finds themselves in, time is often a constraint. Thus, the mobile phone has an advantage over other technologies: "you can talk on the phone even when you're out walking the dog, or whatever you do, but getting set up with a bigger screen … then it's not done in two seconds to get online" (Kjell). To summarize, the team has attempted to use video-based remote assistance with applications such as FaceTime. While it does deliver some value, it still has many challenges. Therefore, mobile phones are still used as the primary tool for remote assistance due to their simplicity and reliability in the function they serve.

4.3 Remote assistance with AR

In a remote assistance scenario with AR, the non-expert streams video from his iPad to the experts iPad. The illustrations below show the non-expert in figure 10, streaming his view to the expert in figure 9. The AR application allows both the expert and the non-expert to draw, place markers and notes on top of the view of the world that is captured by the non-expert's camera and is shared between the two iPads.The expert in figure 9 has drawn a circle around one of the parameters he wished to emphasize, as seen in figure 10. Once a digital object has been placed in the digital version of the real world, as captured by the iPad's camera, it remains in the same location throughout the call between the two engineers.

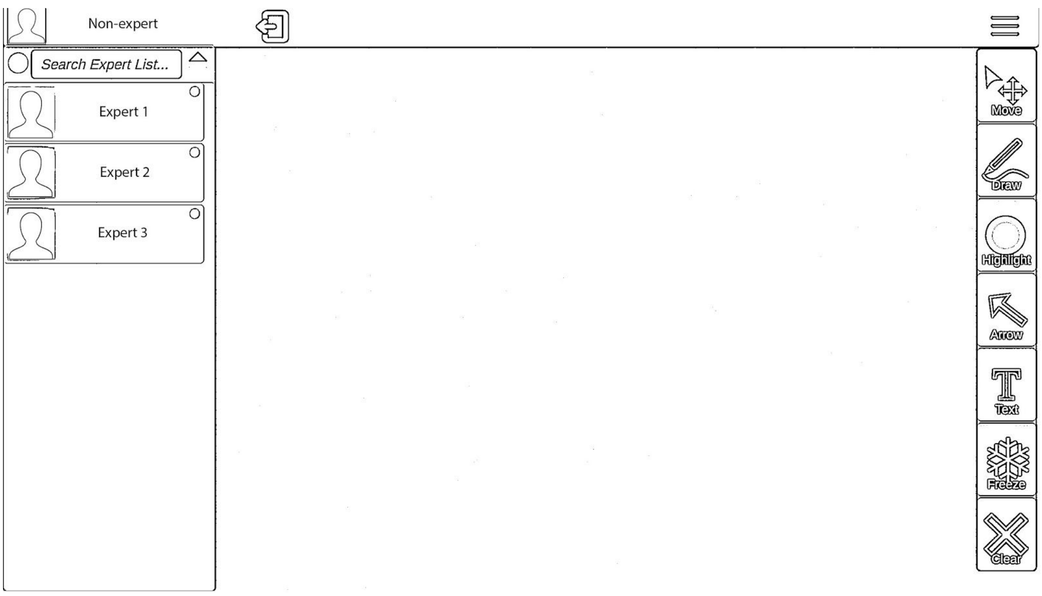
Figure 9: The expert using the AR application on his iPad to guide the non-expert.

Figure 10: The non-expert receiving digital markers from the expert while streaming his view.



The figure below illustrates the user interface in the application. On the left side is a list of experts that can be called, and on the right side is a list of AR tools both the expert and the non-expert can use to communicate. The video stream is in the center. In addition to the tools on the right, both the non-expert and the expert can communicate through a live cursor by drawing on the screen. When a digital object is placed, it can be moved and deleted.

Figure 11: The user interface of the AR remote assistance application.



4.3.1 Competency level

The competency level of the non-expert and the expert affects how effectively knowledge is shared between the two individuals in a remote assistance scenario. After trying AR, the team leader of the PSE-group noted that it can be easier to support non-experts with AR:

> It can become safer, easier to support, a lot clearer that we are looking at the same thing, and that will make it easier, and it will likely require lower competence of the person you are helping, in comparison with explaining things over the phone, because then the tribal language must be much clearer, you need a higher competency level of the non-expert when using a phone for remote assistance (Roar).

In the remote assistance case with Kjell and Joakim, we observed that Kjell as the expert did not particularly use the AR functionality very often. Instead, it appeared a video stream was sufficient to provide remote assistance to the non-expert. When asked about this, Kjell noted that the two of them shared a common language, which made it simple enough for him to explain with words the steps needed to solve the problem at hand:

> But now I spoke with a savvy person, a colleague … we use the same language when speaking of things, so, I think the bigger the difference between he who sits and helps remotely, and he who sits locally, the more relevant it would be, to use markers (Kjell).

Kjell went on to note that the experiments were only done internally in the PSE-group, and that "if we begin to enter two different areas, then it might happen that you need more of that type of functionality [markers]" (Kjell). Lars concurred with Kjell that when helping someone you know and share the same language with, it is easier to be the expert. Furthermore, in regard to assisting someone outside the PSE-group, Lars noted that "it would have been a completely different challenge". Lars went on to note that: "the electrical duty, I don't think it is that relevant … I'm not so sure that they would be able to make use of these tools to the same degree”. The reason Lars does not find remote assistance with AR relevant for the PSE-group to assists others outside of the PSE-group is because of the difference in competency level:

> You need core competence either way. Initially, I don't think it would be relevant to use this outside of this group … at least at our level where we are talking about relatively advanced issues … to guide them [the electrical duty] with the help of these techniques, I have no faith in that (Lars).

To summarize, performing remote assistance with AR can make assistance easier between individuals who have a similar competency level. However, there are conflicting views of how useful the AR functionalities would be in a scenario between an expert and a non-expert with a larger difference in competency levels, such as between an engineer from the PSE-group and an operator.

4.3.2 Mental model

In a remote assistance scenario with AR, an expert is able to see what the non-expert captures with a video camera in near real-time. As the expert can see what the non-expert sees, this means that the uncertainty in the mental model constructed by the expert based on the non-expert’s description of the problem at hand is significantly reduced:

> There is something with explaining a person who you do not see what is actually doing. Then you must construct an image of where he is, what windows he has open, what he is doing. And then give him advice on what to do when you are not... you do not know, you cannot be completely certain about what he has in front of him (Kjell).

Kjell noted that having a video feed was an improvement in comparison to not having it because it removed a lot of uncertainty in the mental model he had to create of the problem. Furthermore, Kjell compared having a video feed with AR capabilities to being present and guiding the non-expert: “because then I am completely on the same wavelength with him …

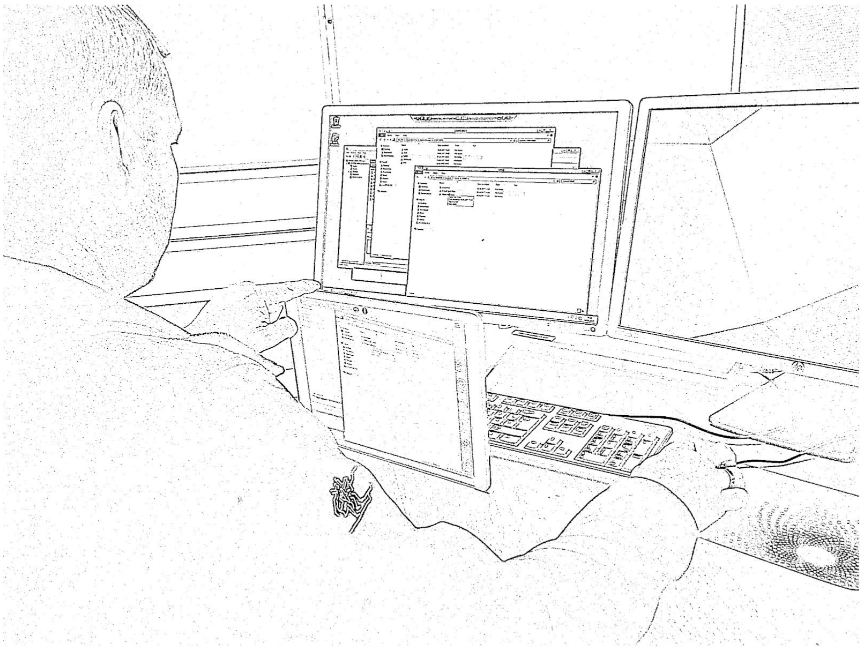
it is just like standing behind his back and guiding him on how to do it" (Kjell). Moreover, as time is a constraint for the engineers when solving a problem, Jan noted how having a video feed can save time: "the pictures you have in your head all of a sudden become a lot clearer, the processing goes much faster then" (Jan). In other words, time can be saved when the expert does not need to spend as much energy on attempting to remember in detail how a system looks like. Additionally, time is saved as the guidance scenario can more easily get to the core of the problem: "you didn't have to spend energy, you didn't have to put words on things, you could use the visual aid to more quickly get to the depth of, the core of the problem" (Lars). In regard to saving energy, Jan noted that any tool that frees energy use is helpful in a remote assistance scenario.

While having a visual feed of the situation was useful to the expert, delivering this feed and receiving guidance at the same time was a challenge for the non-expert:

> There's the image transmission … there's the mouse and keyboard … you need to look at the PC-screen as well … you need to use speech … and then you need to use your ears to hear the explanation, and then there's everything else, maybe you need to walk around and open doors if you're working across stations (Jan).

Having this many things to think of at once constrained the non-expert's ability to provide a stable view of the relevant information. Furthermore, having to think of what the expert is seeing consumes mental capacity: "you look at the screen, and then you see that the iPad is not seeing the same thing, and then you have to adjust it … and all the time it was like that" (Svein). Not having a complete and stable view of the relevant information was also highlighted by many of the engineers as an annoyance when describing their experiences as the expert. Furthermore, we observed several attempts by the non-experts to find a stable way to hold the iPad in order to be able to focus on the problem-solving process. Figure 12 illustrates how the non-expert has to look at the computer screen and the iPad screen simultaneously while holding the iPad steady, and controlling the computer system with his other hand. Apart from this, Jan noted that the non-expert also has to think analytically through the problem-solving process, which adds another layer of complexity to the situation.

Figure 12: Stabilizing the iPad on the desk in an AR remote assistance scenario.



In regard to the mental model that the expert constructs when trying to understand the problem in a remote assistance scenario, one engineer noted that having a visual feed was in fact distracting:

> I found that I was a bit distracted actually, I found it better when you only had speech, then you sit there and think and try to construct that internal image of how the screen looks like … I didn't get the same internal image when I already had an image … I tried [to construct an internal image], but it ended up being kind of wrong actually (Svein)

In the AR remote assistance case where Svein was the expert, we observed the video that Svein had as a source to construct his mental model suffered from network latency causing lag. Furthermore, unstable video due to the non-expert having to hold an iPad and perform operations on a computer at the same time also appeared to be irritating. Thus, it became difficult to fully grasp the situation when the video stream was less than ideal. This caused Svein to find the video stream to be distracting him from constructing a mental model, in comparison to when he did not have a video stream. Without a video stream, he was able to better concentrate on constructing a mental model of the problem based off of oral communication. Moreover, in the remote assistance scenarios with AR, we observed that the experts did not ask as many questions related to the problem as they did without AR: “you ask more questions when you don’t have an image” (Svein). As asking questions is part of the mental model construction process for the expert, we consider there to have been a significant difference in the mental model construction with AR. Apart from a different way of constructing a mental model of the problem, having AR also poses risks.

One of the risks with AR is forgetting which part of reality one is adjusting. In one of the remote assistance scenarios with AR, one of the engineers acting as a non-expert wanted to highlight something in the digital world, but ended up using his mouse to highlight in the real world:

> And then I noticed that I actually used the real mouse instead of the highlight on the iPad … to be aware of where you make adjustments because I could have risked burning down the factory with my highlighting when I was on the system instead of the iPad (Roar)

Roar went on to note that this happened automatically without him thinking of it. We observed that Roar as a non-expert had too many things to deal with at once. Thus, when he wanted to use the live cursor on the iPad to mark something for the expert to see, he was in fact using his real cursor. In a high-risk environment, getting the real and digital worlds mixed up can have severe consequences, which Roar reflected on after the incident. To summarize, AR is useful for removing uncertainty in mental model matching between the non-expert and the expert. However, the construction of an expert’s mental model is constrained by a poor representation of the relevant information when the non-expert has to handle several things at once.

4.3.3 Communication

Communicating with AR allowed the expert to see a video feed sent by the non-expert. Furthermore, the expert had the ability to communicate visually with digital markers that the non-expert could see via his iPad. Jan, one of the engineers noted that the communication became a lot simpler with a video feed: “it became a lot easier when you had a bigger image, it was a lot easier to communicate” (Jan). Instead of being constrained by words, the non-expert could directly show the expert what he saw. Based on this, the expert could either describe in better detail what the non-expert should do next or directly show the non-expert with visual markers. This eased the knowledge sharing process, and the communication was also considered by Jan to be more precise as seeing allowed the expert to more easily remember details in the systems. Furthermore, the requirements from the non-expert to describe precisely what problems faced were lowered compared to using only speech. The engineers still used speech, but the AR tools gave the engineers more ways to communicate. However, the risk of using too many AR markers may lead to confusion and distraction. We observed that Svein was distracted by poor video quality, but a video stream with excessive amounts of AR markers may distract as well. Still, this was not observed in our cases as the engineers did not use the AR markers excessively.

One of the other major advantages of AR is that by seeing what the non-expert sees, uncertainty is reduced between the two communicators in a remote assistance scenario:

> It removes a lot of uncertainty because you are looking at reality … there isn’t any doubt anymore of what is there … when I use a phone there is doubt, it isn’t always that I trust the person sitting on the other end because it does not sound right (Jan).

Without any visual form of communication, Jan noted that he often feels uncertain of the situation described by a non-expert: “yes, you say you are there, but I am a bit unsure if you are actually there … that’s the feeling I get several times”. Roar emphasized that by seeing the same thing, the expert can know for sure, not just make assumptions in regard to the situation based on the descriptions of a non-expert. Additionally, from the non-expert’s point of view, having AR visuals was considered by Gunnar to be reassuring: “it is very reassuring that they [the expert] can point for you and tell you what to do” (Gunnar). Furthermore, if the non-expert lacks the competence to communicate the correct information, then Roar noted that they might proceed to troubleshoot the wrong thing, which in turn would waste time. As time is of the essence for the engineers, precise communication is important in a remote assistance scenario when troubleshooting a critical problem. Furthermore, with AR visuals allowing the expert to exactly point to where the non-expert should make an adjustment, Roar noted that the need for a common language was reduced: “if you can point, then you don’t need to have the same tribal language”. While the AR visuals served as another layer of communication, Lars noted that speech was still the most important tool for communicating: “still, it is the oral communication that is the most important, but with the visuals as a good aid” (Lars). At the same time, Lars noted that when it comes to the details of a complex problem, having a shared visual interface was beneficial:

> It is clear that it is easier when you dig yourself down in the details, you’re going into an application where you need to find a specific module … in an application, a program, a sequence, then it is a big advantage to share something visually … it is not that easy to describe just with words (Lars).

While having a shared visual view of the non-expert’s view was considered beneficial by all the engineers in the PSE-group in relation to communication, Kjell noted that he found the AR markers to be superficial in their cases: “when I see him do it, then I have no need to show anything more graphically on his screen” (Kjell). In other words, Kjell was able to guide the non-expert sufficiently with words when he had a video stream. On the contrary, Roar noted that AR markers make it possible to work through a non-expert. In the cases we observed, the PSE-group were assisting each other. As the engineers in the PSE-group have a similar competency level, Kjell found AR markers to be superficial, as he was able to communicate sufficiently with oral communication. Roar, on the other hand, could see the opportunity of the AR markers as a useful tool for communicating more easily with non-experts of a lower competency level. AR markers open up the possibility of being extremely precise in communicating what needs to be done, which makes it possible for an expert to work through a non-expert that has close to zero knowledge on the given problem. While Roar saw the opportunity in this, we did not get to observe such a situation. To summarize, AR improves communication by adding more layers of communication between the non-expert and the expert. However, the usefulness of AR markers is perceived differently by the different engineers.

4.3.4 Learning

With AR, both the sender and receiver of knowledge can learn in a remote assistance scenario. With a shared visual feed of what the non-expert sees, the expert can become more engaged in what the non-expert is experiencing. Furthermore, the non-expert can receive a higher accuracy of guidance through visual markers. Compared to only having oral communication, Jan noted that in a recent scenario he believed they would have been able to get further in the problem-solving process with AR:

> I am sure that with AR you would have gotten further into it, possibly even solved it. And if you can follow someone from A to Z, that creates sort of a common thread through the whole thing. Then you know yourself why you started with that, why we went through there … then there's learning from that I think.

Getting further would have improved learning because the remote assistance process would not have had to be aborted. In other words, the further you can get in a problem-solving process remotely, the more can be learned. Furthermore, in a remote assistance scenario with AR, the expert guides the non-expert and allows the non-expert to perform the actions himself. A regular remote assistance program for computers allows a remote expert to directly take control over another computer. However, the PSE-group do not make use of these programs because they open up the possibility to remotely control the systems the PSE-group operates. This poses a severe security risk. Furthermore, compared to a remote assistance program where the expert takes control of the system, Jan noted that as a non-expert, he learns better by performing the actions himself:

> It's like when someone is going to show me something technical that I need to learn … then I say, "can't I do it myself, and then you explain it to me" … you remember better, what you do yourself, so I think that is positive, that it has a positive effect on the person who is sitting and doing it.

While performing the actions yourself can improve learning, Jan noted that learning also depends on interest. If the non-expert is not interested in learning, but only interested in having the problem solved, then the effect of AR on learning in a remote assistance scenario is likely to be insignificant. However, if the non-expert has an interest in learning, then with visual markers, the expert can more precisely guide the non-expert. Gunnar, the most senior engineer noted that having the ability to show and point with digital arrows can improve learning. Pointing is a natural way of expressing guidance that we observed was the most natural form of using AR markers between the engineers. On the other hand, Lars noted that there is a danger of becoming too reliant on the expert:

> But there is a danger with it, that you possibly become too dependent on the expert, and then you become the performing [person], without you actually reflecting over what you have done … If you just sit in front of the screen instead of deep diving into the issue and relating to the issue yourself … just being told what to do, then the learning outcomes are poorer (Lars).

This is in contrast to Roar's notion of using AR markers to work through a non-expert with a low competency level. Lars highlights an important aspect of the learning process, which is becoming involved in the problem-solving process. However, in our observations, we did not notice any significant difference in how involved the non-experts were with and without AR. At the same time, all the engineers we observed had a similar competency level. Thus, we may have observed different levels of involvement with AR had we observed a non-expert of a lower competency level. To summarize, AR can improve learning when there is an interest to learn from the non-expert. On the other hand, AR can reduce learning if the non-expert becomes too reliant on the expert.

4.3.5 Technological aspects

The PSE-group found the AR software to be easy and intuitive to use. The expert in the scenarios was able to share the knowledge that was needed by the non-expert, and the latter was able to solve the problems given by using this knowledge. The training given to the engineers before using the technology was brief, yet the team did not have any problems using it: "What surprised me was how easy it was to use, it had its weaknesses, but it was easy to use ... and if you have the right person on the other end then it is of great aid" (Lars). While Lars did not experience any problems with the application, not every case went as smooth.

In a few of the cases, we observed some difficulty starting the application. Yet, by closing and reopening the application, it would work as intended again. Having an application that is reliable is important: "it is absolutely crucial that it works … for it to be the preferred choice for remote assistance so that it does not become like FaceTime is right now … could become more frustrated by that" (Jan). While the team noted that the technology was intuitive to use, all of them reported that the biggest annoyance throughout the remote assistance scenarios was not having their hands free as non-experts. As noted by Jan: "it must be fixed to something, you have to have your hands free". Without having their hands free, we observed the non-experts struggling to hold the iPad while troubleshooting the problem at hand and receiving remote assistance at the same time. This was also an annoyance to the expert, as the non-expert constantly had to put the iPad down, which meant that the expert would lose focus of what the non-expert was seeing:

> Then you lose a bit of the journey …You're going from one point to the other and if you take away pieces of it then I think it can be hard to, in a way you get lost, at least the one [the expert] who is watching (Jan).

In regard to the AR markers, we observed that while the team knew of them, they were not often used. Jan noted that when the video stream was not stable, it was hard to precisely place the AR markers:

> In a live image then those markers didn't work that well for me, at least not when the movement is there, then I would rather prefer using a still image, then I could show the markers on the still image (Jan).

Kjell further noted that imprecise markers can be a danger, as the team works on highly safety-critical systems. For example, should the marker be placed on the wrong button, this poses a safety risk. Thus, we observed the team to use the freeze functionality when they wanted to place AR markers. This was observed to be useful, as freezing also allowed for zooming and panning. Svein noted that he intuitively attempted to zoom and pan around when he first tried the software as an expert, but was disappointed that this functionality did not exist in a live image: “because you’re used to using an iPad, and used to panning back and forth, but that didn’t work .. because there was someone else controlling the screen … that was a little strange” (Svein). Still, the most useful part of using AR technology was described by Lars as having a shared visual interface: “I think there is something with having a shared visual interface, that’s initially what is most useful”. Kjell further noted that in his cases, having a shared visual interface in addition to voice was sufficient, he did not need extra AR markers. Furthermore, Lars noted that having something that would free the non-expert’s hands would be the most useful: “Having an interface that would always follow your gaze, not having to use a pad which you frantically must try to hold in a stable position while you use a keyboard … it would have been a great leap.” To summarize, the biggest complaint from the PSE-group with the technology was not having their hands free as non-experts. Furthermore, the AR markers were not always found to be as useful. Still, having a shared visual interface combined with oral communication was useful.

4.4 Summary

To summarize our empirical findings, the table 5 on the next page provides an overview.

Table 5: Overview of the empirical findings.

	Without AR	With AR
Competency level	- Easier to communicate when competency level is similar - Competency level is similar within PSE-group - Competency level can vary a lot outside of PSE-group - Competency level comes mainly from experience - Being aware of competency level of others is important when sharing knowledge with them - The higher the competency level, the more complex questions are asked in remote assistance scenarios, and vice versa - Attempting to guide someone with a low competency level can lead to mistakes being made, which can be dangerous	- AR allows for a lower competency level of the non-expert in comparison to remote assistance with a cell phone - The greater the difference in competency level, the more useful AR markers can be - Core competence still needed when using AR and AR markers. Unlikely to be of help in complex situations with non-experts without core competence.
Mental model	- With strictly oral communication, the engineers have to be very systematic when troubleshooting - It is hard to remember every detail of a computer system without seeing it in a remote assistance scenario - High degree of uncertainty when using strictly oral communication to convey mental models of complex computer programs	- With a real-time video, the uncertainty of what the non-expert is experiencing is significantly reduced - Time to construct a mental model of a situation is significantly reduced when the expert can see the situation - Easier and quicker to get to the core of the problem - Hard for the non-expert to keep a stable view of what he sees - Difficult for the non-expert to handle filming, listening, speaking and troubleshooting at the same time - Fewer questions are asked by the expert when video was present - There are risks involved when it is possible to forget which reality one is interacting with
Communication	- Communicating in person is the most effective - Remote assistance scenarios require trust between expert and non-expert, especially in high-risk environments which the PSE-group operates in - The PSE-group share a common language	- Easier to communicate when the non-expert and the expert can see the same thing and speak of the same visual representation - By seeing the same thing, the expert can get instant verification that his guidance is being acted upon correctly - From the non-expert's point of view,

	- There are different cultures and different languages between the groups working in Chemical Co. - Those who work on the same systems can more easily be precise with each other in oral communication - With strictly oral communication, important information about a situation can be lost if the non-expert does not know what information is important	it is reassuring that the expert can point to exactly what actions to perform - AR markers are at times considered superficial and oral communication is considered sufficient
Learning	- Continuous learning is necessary for everyone in the PSE-group as all the systems change continuously - As the team members have to learn from each other, teaching is just as important as learning - The team members are constrained by time and therefore do not always reflect to properly learn from a situation as they have to move on to the next problem - Problems occurring are diverse and extensive amounts of time may pass between each similar case. Thus, learning from few samples is hard	- The expert can become more engaged in what the non-expert is experiencing - Learning can improve as it is in general possible to get further and deeper down into the problems with AR - By still allowing the non-experts to perform the actions themselves, they can learn more - With AR there is an increased risk of becoming too reliant on the expert's guidance
Technological aspects	- To address limitations of oral communication, FaceTime has been experimented with. However, video quality has been unreliable and poor, making the application less than ideal - With FaceTime, there are too many things to handle at once: filming, hearing, speaking, and troubleshooting - Screen sharing capabilities would have been beneficial. However, screen sharing applications are not used due to safety concerns. - Cell phones are quick, reliable and accessible. Therefore, they are the primary remote assistance tool currently in use	- The AR application was intuitive and easy to use - The most significant weakness from the non-expert's point of view was not having their hands free - With too much movement in the video, placing AR markers was difficult - Imprecisely placed markers can pose a risk as they can be wrongly acted upon - The greatest benefit was not with the AR markers, but with sharing a visual interface

5 DISCUSSION

In this chapter, we will discuss our findings. Thereafter, the limitations of the study will be discussed before we present suggestions for future research.

5.1 Sharing knowledge in remote assistance scenarios

The purpose of this study was to determine in what ways remote assistance with AR can be valuable for knowledge sharing. We have found that to provide on-demand support around the clock for all the systems the PSE-group maintains, the team is dependent on sharing knowledge both between each other and to any other employee who requests their expert help. Furthermore, we have found that knowledge sharing often occurs remotely as the experts are not always able to be present where the problems occur. Currently, the team uses cell phones to provide remote assistance. While the cell phone is an old and proven technology, it constrains communication to speech. We have found that oral communication can be an effective way to share knowledge. For example, when the problem at hand is of low complexity and when the non-expert can sufficiently describe the necessary details for the expert to understand the situation. However, with a high complexity problem and a situation where the non-expert does not have a sufficient knowledge base to understand the guidance given by the expert, the remote assistance scenario may end up being aborted. Thus, depending on the severity of the situation, the expert may have to physically approach the problem. Such a situation can be costly when the problem is severe. For example, if an important production unit should stop working and the expert must travel to the location of the problem.

When oral communication has been a constraint, we have found that the team has experimented with video-based calling through the iPhone application FaceTime. We found that this application has limitations in that it is not specifically designed for remote assistance use cases. Particularly, the size of an iPhone is small, and the lack of reception in certain areas of the production facilities has resulted in poor image quality. We found this to be equally challenging in our experiments. Still, the application we tested was specifically designed for remote assistance use cases. Furthermore, due to the size of the iPad, the expert could more clearly see what the non-expert filmed. With a shared visual interface, we found improvements in learning and communication. Furthermore, we found that mental models can be easier to construct for an expert when a live image is available. Finally, remote assistance with AR can be easier in situations where the gap in competency level between a non-expert and an expert is large. From the empirical data we found five themes that affect knowledge sharing in remote assistance scenarios. In the following sections, how these themes affect knowledge sharing will be discussed in more detail.

5.1.1 Competency level

We have found that competency level is a critical factor that affects remote knowledge sharing with AR. This specifically relates to the similarity or difference between the competency level of the expert and the non-expert, as well as the degree to which they are aware of each other's competency level.

Differences in competency level

First, our findings from the data without AR shows that the process system engineers experienced remote assistance to be very challenging when there is a big gap between the competency level of the non-expert and the expert. The engineers noted that it can be very challenging to remotely share knowledge on a system the non-expert has very little previous knowledge on. This may be explained by the fact that the expert and the non-expert are situated in different personal and cultural worlds which colors how they understand and interpret the same knowledge. This is in line with Ackerman, Dachtera, Pipek, and Wulf (2013) who found that when knowledge is shared across a specific personal and cultural boundary, some meaning will be lost because the knowledge is deeply embedded in its contextual origin. According to this statement, the bigger the gap in competency level, the more of the initial meaning will be obscured.

Moreover, the problem related to the competency gap can further be divided into two problems: (1) competency level affects the ability to use correct and precise language and terminology, and (2) different remote assistance media will provide different levels of access to the expert's knowledge base as well as the quality of the de-contextualization process. These problems will affect the quality of knowledge sharing with remote assistance.

The first problem is concerned with the relationship between competency level and the ability to communicate with the correct tribal language. A similar relationship can be found in Knorr-Cetina and Mulkay's (1983) concept of "native competence", which explains the dynamics of working within a certain knowledge base and how this affects the language used to externalize and interpret objects. This relationship can be seen in the following statement by Roar: "we use a larger vocabulary of the tribal language when I speak with my boys than with the electricians". Consequently, if the competency gap is large, the use of a tribal language will decrease. This clearly indicates that if the expert tries to use too complex or technical terminology to explain things precisely, this will create unnecessary ambiguity and lead to misunderstandings. One reason for this may lie in the fact that the experts operate based on their respective CoP's internally shared system of meaning which may cause them to filter out essential information (Dougherty, 1992), such as which level of language complexity is suitable. Moreover, the non-expert will have difficulties absorbing knowledge when he does not share a common platform of understanding with the knowledge source (Cohen & Levinthal, 1990). Additionally, a lower competency level in the non-experts will make it more difficult for him to actually explain and convey what the problem is, even though he may understand it himself. This is in line with Gorman (2008) who found that enough of a shared language must exist to facilitate teamwork. Thus, when people do not share competency level they will also struggle to be able to use the same tribal language that is required to communicate to create a shared understanding of the problem and the context.

The second problem is closely related to the degree to which different remote assistance media enables access to the expert's explicit and tacit knowledge base. For the PSE-group, the remote assistance medium's potential to provide tacit knowledge sharing is important because the problems they face are "too complex … a manual would not be possible" (Jan). Thus, there is a demand for a remote assistance medium which facilitates more than just explicit knowledge sharing such as sending emails or writing down manuals. To access more of the expert's tacit knowledge, the PSE-group have been mostly using oral-based remote assistance such as mobile phones and video-based remote assistance such as FaceTime.

According to Clark and Brennan (1991), mobile phones facilitates the process of accessing the expert's knowledge base through audibility, co-temporality, simultaneity, and sequentiality. In addition to these four factors, visibility and to some degree co-presence is included in FaceTime. In AR however, visibility and co-presence are to a much larger degree represented. Thus, when progressing from mail to phone, to FaceTime, to AR, there is a gradual increase in the possibility for the non-expert to establish a common ground in the tacit knowledge embedded in the expert. Therefore, the non-expert is able to access more of the expert's competence and authority with richer remote assistance media which facilitates a higher quality of tacit knowledge sharing. This corresponds to the theory of tacit knowledge sharing emphasizing socialization, shared experiences and real-time collaboration (Ackerman et al., 2013; Nonaka & Takeuchi, 1995; Polanyi, 1966). Furthermore, this enhances the descending process of understanding where knowledge can be de-contextualized in relation to the expert, which is the source of a particular tacit understanding (Ackerman & Halverson, 1999). Therefore, it can be concluded that AR makes it possible to leverage the intrinsic value of the expert's competency level to a larger degree than what is possible through a phone.

Even though the expert will be able to convey more of his tacit knowledge through AR-based remote assistance, this does not mean that the non-expert needs a higher competency level as well. On the contrary, when comparing oral-based remote assistance to AR-based remote assistance, Roar expressed that "it will likely require lower competence of the person you are helping, in comparison with explaining things over the phone". This may be because the tribal language has to be much clearer when one is explaining things over the phone, as most of the communication has to be expressed explicitly. Therefore, a higher competency level of the non-expert is required when using a phone for remote assistance. With AR, on the other hand, the need to express everything explicitly is reduced because of the possibility to highlight an object without necessarily knowing the correct technical terminology. This is not to say that the non-expert can be completely clueless. Lars noted that the non-expert needs a knowledge base to make use of the added benefits of AR. This is in line with Bower and Hilgard (1981) who stated that prior competence increases the chance of perceiving new patterns that can be associated with similar concepts and ideas already stored in memory.

Proposition 1: A large gap in the competency level between an expert and a non-expert can be compensated by introducing video- or AR-based remote assistance.

Similarities in competency level

As larger differences in competency level increase the need for AR-based remote assistance, one would expect that a similar competency level would reduce the need for AR. On one hand, this can be supported by the fact that a similar competency level will enable communication with a larger degree of shared language with more technical and precise terminology, and thereby reduce the need for AR. On the other hand, the value and need for AR can be seen in other ways even though one shares competency level. The most apparent advantage is related to AR's ability to facilitate cooperation within communities of practice. In these communities, there is often a shared competency level. As stated by Wenger, McDermott, and Snyder (2002), it is crucial for a CoP to "build a fire in the center of the community that will draw people to its heat" and "engage members into more active participation" (p. 58). There is big variety in the different remote assistance media to do just this. It can be argued that if a community is only able to cooperate through oral-based remote assistance, this is just like pouring water on the fire in which you are trying to light because it is much more difficult to access tacit knowledge via explicit oral communication. For equally competent experts at the center of these communities to fuel this fire, a remote assistance medium that facilitates shared experiences and tacit knowledge sharing is required. Thus, AR is of great benefit even though there is a big similarity in competency level. Furthermore, from the fire created by these experts, other people who may not share competency level with the experts may leverage the benefits of this strong remotely connected CoP.

Proposition 2: With AR it is possible to leverage the similarities in competency levels as this will enhance the communication within CoPs.

Awareness of the other's competency level

In addition to competency level as an important factor when communicating, the awareness of the other's competency level is also crucial. This is important because one needs to know what terminology to use. Boland and Tenkasi (1995) argue that the awareness of what others know is the first step in enhancing interaction. Our empirical data show that there is a clear connection between knowing people and knowing their competency level in regard to knowing how much knowledge an engineer is able to share in a remote assistance scenario. The theory also emphasizes the capacity of adopting the perspective of others because it is essential for collaboration, coordination, and communicative competence (Krauss & Fussell, 1991; Rommetveit, 1980). If for instance, the expert lacks insight into the non-expert's competency level, then he might communicate with unnecessary complex terminology that will increase ambiguity and cognitive load. Therefore, an expert needs to be aware of a non-expert's response to verify whether what is being said is being understood or if a simpler terminology is needed. However, oversimplification will leave behind important nuances and details which is necessary for complete understanding. Therefore, awareness is key to find the correct balance.

Furthermore, competency level in the form of tacit knowledge is reflected in the actions and activities of the individual (Nonaka & Takeuchi, 1995; Polanyi, 1966). It is therefore important to pay attention to what the other person is doing, in addition to what he is saying to more fully understand his competency level. Because one is not able to see what the other person is doing with oral-based remote assistance, one needs to hear attentively, not just listen passively, to be able to perceive the other person's level of competence. Additionally, with AR one also needs to see attentively, and not just look passively. Even though this requires increased awareness and active participation, AR makes it easier to increase the awareness of what is being communicated as it includes more senses in the communication. An example is a person who's talking on the phone, but he is not paying attention because there are so many interesting things his eyes are glancing over. Thus, when one is only listening, there is always the risk of the mind drifting to many other things. But when one is engaging more senses in an activity, like the sense of sight, it may be easier to control the mind. Thus, AR automatically increases awareness and focuses attention, which makes it easier to directly perceive the other person's competencies and competency level.

Proposition 3: AR will make it easier to be aware of the other's competency level by increasing awareness and focusing attention on what is being communicated.

5.1.2 Mental model

When a non-expert is met with a problem, he will construct a mental model, also known as a "dynamic, simplified, cognitive representation of reality" (Burke et al., 2006, p. 1199). If the non-expert needs remote assistance and does not have access to AR, the non-expert will try to describe the problem to an expert. Then, the expert must construct his own mental model based off of this description. In comparison to being present and experiencing the problem for oneself, this can introduce a lot of uncertainty for the expert, as he cannot be sure how accurate the non-expert's mental model of the problem is. Depending on the situation, this uncertainty can be enough to abort a remote assistance scenario, should the risk involved with attempting to guide in solving the problem remotely be too high. As the team maintains operation critical systems, making a mistake can lead to severe economic damages as well as safety hazards towards other employees. This uncertainty is described by Kjell: "and then give him advice on what to do when you are not actually... you do not actually know, you cannot be completely certain about what he has in front of him". Dealing with uncertainty in a high-risk environment can lead to stress. Lars noted that many of the remote assistance situations can be stressful because there is a lot at stake. Thus, we believe that any tool which can reduce uncertainty in remote assistance scenarios would be valuable to the engineers. However, not all the engineers were convinced of the benefits of a direct video stream with digital markers.

Before trying the AR software with iPad's, the PSE-group had experimented with using FaceTime on their iPhones. One of the issues the team experienced with this approach was the poor image quality, often leading to more frustration than just using an oral-based phone call. In the cases with AR, the image quality was not always perfect. We observed that this was a source of frustration. Constructing a mental model based off of fuzzy video appeared to be challenging. Svein mentioned how this lead to him being distracted, he also mentioned that he found it "better when you only had speech, then you sit there and think and try to construct that internal image of how the screen looks like … I didn't get the same internal image when I already had an image". It appears that with an image already there, Svein does not construct a mental model in the same way. Furthermore, it appears that if the image is of poor quality, then not having one at all could have been more beneficial. Svein also mentioned how he asks more questions when he does not have an image. This coincided with our observations of the whole team, they did not explore each other's mental models as much when they had video. This can be a weakness, as it appears oral-based communication decreases in remote assistance scenarios with AR.

Proposition 4: Video- or AR-based remote assistance reduces the uncertainty in the expert's mental model.

With AR, the non-expert streamed his view to the expert. Thus, the expert no longer had to solely rely on the non-expert's description of the problem, as he could see it for himself. Thus, a lot of uncertainty was removed when the remote assistance scenario had video in it, not just speech. Furthermore, Jan noted that the pictures he had in his head "all of a sudden became a lot clearer, the processing goes much faster then". In other words, the construction of a mental model of reality is easier when one has a more accurate view of reality. This in comparison to not having a visual representation which would leave more of the construction of a mental model up to interpretation. Albrecht and O'brien (1993) noted that mental models only represent a fraction of reality as they are colored by an individual's subjective perspective. With a live view of reality, this subjectiveness can be reduced. Furthermore, Jan mentioned faster processing, this is likely since he did not need to spend mental capacity to construct an internal image of what something looks like when he had a direct visual representation. Lars also spoke of this: "you didn't have to spend energy, you didn't have to put words on things, you could use the visual aid to more quickly get to … the core of the problem". This is in line with Porter and Heppelmann (2017) who note that having contextualized AR visuals can reduce cognitive load.

Proposition 5: Video- or AR-based remote assistance can reduce cognitive load for the expert by providing a visual representation of reality.

5.1.3 Communication

Explicit precision

In oral-based AR "it is very important to be precise" (Joakim) to share explicit knowledge. However, it is nearly impossible to communicate with perfect precision if one does not share competency level, and thus also a common, highly technical language. The problems regarding precision were highlighted by Jan after one of the cases we observed: "If both me and Roar had been more systematic, then it would have been better … If we only had been more precise. However… it is impossible to be precise on everything, one cannot describe everything". This statement points to why the process system engineers emphasize precision in explicit oral-based remote assistance and is supported by the following excerpt from Kristian's reflective observation remarks during Roar and Jan' case without AR:

> They are very systematic. It seems like having an overview of the problem at hand is what is most important. I have noticed that they work with a very 'logical' mindset. This may be because they are used to thinking in layers, for example when Roar started going through the structure of the problem he started from the root and went down each layer: 'module - reference - row - action block - expression - and in that expression we see a code'. And during the remote assistance scenario, it is important that both the non-expert and the expert follow each other distinctly through each layer and if they do not 'see where they are', they go back another layer and begin from a slightly higher perspective.

From this, we can see that the process system engineers must be systematic and precise when remotely assisting each other. First, most of the problems the PSE-group are faced with on duty is of a troubleshooting nature where finding the problem is key. When the problem is found, the solution is often given and "simple". This stands in contrast to creative problems where there may be many solutions and abstract concepts with overlapping meaning which can be interpreted differently. Second, to solve troubleshooting problems, they must be systematic in their approach. This is especially important as they are working on many different levels as indicated in the statement above. Furthermore, if they suddenly lose track of where they were in the problem, they must start over again at a higher level to regain an overview. This is explained by Jan: “Now the error was that me and Roar talked on two different levels, only that I talked on a lower level. It was the same interface but on different levels”. Thus, even though the engineers try their best to be precise and systematic during oral-based remote assistance, establishing a sufficient common ground using strictly explicit knowledge sharing can be challenging.

Proposition 6: Imprecise speech when sharing knowledge explicitly may lead to a failure in establishing a sufficient common ground in communication.

Tacit visualization

Precision in explicit communication is still possible even with the introduction of AR. However, the nature of explicit knowledge sharing changes. During our observations, we observed that the participants started using shorter, more imprecise words and phrases as exemplified by Svein and Lars: “Go up to that menu, green and red, it changed, I thought it was the same” (Svein). “It must be this one” (Lars). “Yes, it is interlocked” (Svein). “This was also interlocked” (Lars). In this case, words like “this”, “that”, “here”, and “there” were often used together with the AR highlighting markers. This simple and effective communication indicates that the precision previously conveyed by strictly expressing oneself orally is equally satisfied through AR in other ways. This is in line with the understanding that explicit knowledge cannot be possessed by itself, but “must rely on being tacitly understood and applied” (Polanyi, 1966, p. 7). Hence, a particular tacit understanding can be communicated in different explicit ways, either through speaking or through visualization. Thus, even though it may look like one is communicating in two different explicit ways when one switches from oral- to AR-based remote assistance, one is still able to communicate the same tacit knowledge from which the explicit knowledge is grounded in.

Furthermore, because the same amount of tacit knowledge is transferred in an easier and more time-efficient manner, it can be argued that explicit visuals lie closer to the tacit dimension of knowledge than words do. This is in line with Jasimuddin, Klein and Connell’s

(2005) argument that there exists a graded continuum between explicit and tacit knowledge. This is also supported by Jan as he considered being able to see video and visuals enabled him to more easily remember tacit knowledge compared to when he only had a phone: "The pictures you have in your head suddenly becomes much clearer ... when they can be seen via AR, then it's more self-evident. It's not like it's the first time I see those pictures." The increase in accuracy can be understood by referring to a greater recollection of deeper embedded tacit knowledge. This suggests that visuals enhance perceptual resources such as processing and memory as well as pattern recognition which is in line with the findings of Card and colleagues (1999). However, it should be emphasized that AR visuals are still no complete substitute for oral communication. This is because explicit knowledge that lies closer to its tacit origin, may also have more of the inherent characteristics of tacit knowledge such as irreducible uncertainty and causal ambiguity (Polanyi, 1966; Szulanski, 1996). Thus, even with AR-based remote assistance, it is important to keep enough contextual explicit information that is necessary to understand the tacit knowledge. As a conclusion, AR-based remote assistance has a larger potential to enhance remembrance and a mental association between explicit knowledge and the tacit knowledge it is grounded in.

Proposition 7: AR-based remote assistance has a larger potential to convey more tacit knowledge compared to oral-based remote assistance.

A common ground in communication

The creation of a common ground is the foundation for communication (Clark & Brennan, 1991). More specifically, it is the most essential prerequisite for high-quality communication, which means that a common ground must be established before one can communicate in a precise and efficient way. This foundation is to some degree established before the communication starts, because the individuals may share mental models, competency levels, and language. However, this process of establishing a common ground continued when the actual communication started. According to the different media used during the remote assistance cases, we observed different attempts of trying to establish such a common ground.

With oral-based remote assistance, the effort of creating a common ground in communication primarily took place by two means. First, through the process of speaking and thinking in a systematic, logical and precise way. Second, through mentally focusing, remembering, and visualizing the information presented. As there were no other ways to enhance and maintain a common ground over time other than continuing to speak or continuing to remember and visualize, this required high cognitive load, quickly overloading the individual's cognitive capacity. This despite cognitive load being reduced due to cognition being distributed between the individuals (Yu, Hao, Dong, & Khalifa, 2013). The negative effects of overloading cognitive capacity were especially seen in the oral-based remote assistance case between Jan and Roar. Here we observed that both were so focused on using all cognitive capacity on communicating precisely and fixing an image of the problem in their minds at all times, that it was difficult for them to be flexible to consider if they, in fact, did not have the same common ground. According to Porter and Heppelmann (2017), and Card, Mackinlay, and Shneiderman (1999), the solution to this problem would be to outsource cognition externally into video and AR visuals. This would not only reduce cognitive load but also add video and visuals to the common ground. However, the difficulties in trying to establish a common ground in communication were also observed in the cases with AR.

Even though there was a reduction in spoken words and an increase in tacit visualization, there was much cognitive load spent on establishing a common ground in communication with AR. More specifically this was in regard to the AR device being handheld: "Move more to the center and little bit closer, a little bit up, closer, zoom in to where the mouse was". Thus, before any problem-specific communication occurred, a lot of cognitive load was spent on trying to synchronize the perspectives and the visual fields of the expert, the non-expert, and the handheld AR device. We observed that when these perspectives were moving towards unification, or up to the point where they were unified, there was a gradual increase in problem-specific communication. This is in line with Daft and Lengel's (1984) argument that rich communication media, such as AR, will reduce ambiguity by reducing divergent frames of reference. However, this process of unifying the different perspectives and visual fields required a lot of cognitive load in addition to interrupting the problem-specific communication. Thus, cognitive capacity was also overloaded during the cases with handheld AR.

Being able to embrace more perspectives simultaneously requires a substantial amount of cognitive load and thus cognitive capacity is overloaded when the two visual fields are not synchronized. Even though handheld AR devices are able to provide increased tacit visualization, they work against what we believe to be the main value of remote assistance with AR: to establish a common ground in communication with as little cognitive load as possible. Jan supported this view: “anything that frees up energy on all the things one needs to do, it does not really matter what it is”. Adding to this conclusion is Porter and Heppelmann’s (2017) argument that AR’s value lies in not having to translate between different contexts such as 2D, 3D or different visual fields. Thus, while a handheld AR device is not able to facilitate the creation and maintenance of a continuous common ground in communication, a head-mounted AR device may do so.

Proposition 8: With oral- and AR-based remote assistance, a lot of cognitive effort is spent on trying to establish a common ground in communication.

5.1.4 Learning

The perspective and purpose an individual may have with regards to learning are to a large degree determined by the context in which the learning takes place. The contextual factors and its impact on learning is substantiated by Land’s (2000) theory of how open-ended learning environments affect learning behavior with certain limitations. The contextual factors impacting learning in the PSE-group is presented in our empirical findings: (1) an expert on duty is expected to “know everything, but nobody can know everything” (Svein); (2) Even after a learning process has happened, due to limited cognitive capacity, it “might be forgotten after two weeks, so even if the same problem occurs the next time, you’ll still get a phone call” (Jan); (3) The PSE-group must constantly learn and stay updated on the systems within Chemical Co. because they are continuously being updated; (4) the most commonly applied strategy to handle the vast amount, variation, and complexity of problems is “often putting out a fire” (Joakim). In short, learning may be difficult because there is limited time and there is a vast amount, variety, and complexity of problems. Consequently, it can be argued that this context is shaping the engineers’ view of learning to be more concerned with the short-term perspective. Thus, this short-term perspective may work against the cognitive requirements necessary for learning to take place in an open-ended learning environment. One of these learning requirements is to be actively engaged in analytical reasoning as well as challenging naive preconceptions one might have to “integrate new and prior knowledge" (Land, 2000, p. 68). However, it should be noted that the PSE-group makes monthly attempts to share knowledge within their group through their monthly duty training sessions. Furthermore, it can be argued that these seminars do not have the primary aim of increasing the competency level of the non-experts in a way that they will be able to perform these tasks themselves.

Learning context and learning perspective

The main focus of the PSE-group in the monthly duty training sessions have been to give the non-experts a general overview of the structure and functions of the different systems. The importance of seeing the overall structure of a problem and being able to know where you are in the problem has been emphasized several times:

> First, it is a question about structure … I need to communicate what, where it is I am working now right. Starting from an image of the screen, I am going to dig my way in, then delve further in, I need to find the logic, I need to find the program. There can be many program components consisting of more components, localized at a place in a controller, a module, which again consists of other things ... I need to explore the structure right (Lars).

The learning is therefore not meant to give in-depth understanding to the non-expert, but it is meant to give the non-expert a general understanding of the structure of a system. Instead of trying to get all the non-experts up to the same level of understanding as the experts which would require a lot of resources and time, their focus has been on teaching the non-experts general knowledge. This general knowledge base will make it easier to leverage the knowledge of the expert and facilitate the assistance of the non-expert into the intricate details of each case. When a problem arises, it will be easier for the expert to extend his thinking, actions, and assistance through the non-expert. This is in line with general-to-specific learning theory (Campos, Ericsson, & Hendry, 2005), except that it is only the general that the non-expert learns in the monthly duty training sessions, while the specific is executed with the assistance of an expert. Thus, the problems are solved, even if it's at the expense of the non-expert's learning.

The decision to learn only the general may be connected to the need of solving problems in a practical, realistic, and time-efficient manner. This decision seems to be based on the awareness that organizational resources are limited and that individuals are rationality bounded (Kahneman, 2011). However, it is important for the PSE-group to also be self-aware of their perspective on problem-solving and learning because it may have much bigger consequences with AR compared to oral-based remote assistance.

When going from oral- to AR-based remote assistance, there is a risk of the non-expert becoming more passive which may inhibit learning experiences. This is because less is required of the non-expert with AR-based remote assistance. For instance, the non-expert does not need to explicitly explain what he sees because the expert already sees his visual field. With oral-based remote assistance, however, a constant knowledge sharing dialogue is required to gradually and iteratively establish a common ground as well as an understanding of the problem. This is not necessarily the case with AR as it's possible to become too dependent on the expert without reflecting on what is being done: If you just sit in front of the screen instead of deep diving into the issue and relating to the issue yourself … just being told what to do, then the learning outcomes are poorer" (Lars). Consequently, as a result of taking a more passive role, the non-expert may become less motivated or engaged in the knowledge sharing process. The non-expert may also feel that he is no longer being assisted to perform a task, but is instead being controlled or instructed even down to the most tedious detail like where to click and how the iPad should be held. As a result, learning is inhibited together with decreased motivation and engagement. This is in line with Salomon's (1985) argument that learning, or internalization of knowledge as he puts it, is strongly tied to the degree in which the learner willingly engage in the technology. Additionally, the expert needs to acknowledge that more of the responsibility of explanation falls on him if learning outcomes are to be enhanced, or at least to prevent the loss of learning. Therefore, it is crucial that the process system engineers are aware that AR may increase some of the negative aspects related to having a short-term perspective on problem-solving.

Proposition 9: AR-based remote assistance may lead to more passive non-expert's which can reduce the learning outcome from remote assistance scenarios.

Learning by teaching

There is also a danger of reduced learning from the perspective of the expert with the introduction of AR. With AR, the expert does not need to explicitly verbalize what he is thinking. Instead, he can use the visual markers and cursors to indicate the same thing. According to Gunnar, this would then negatively impact learning as "you learn more from teaching than being taught, because then you have to put words on it". This type of learning may be more correctly termed re-learning. This is in line with Brady's (1990) suggestion that the process of 'remembering' involves a reconstruction of previously learned knowledge that had in some ways been 'dismembered' by the continuation of new experiences. Further, the process of recounting past knowledge in front others provides a unique opportunity for stimulation and re-appropriation of matured learning experiences (Cortese, 2005). Thus, if the expert only uses AR to extend his actions through a passive non-expert without explicitly putting words to his reflections, he will lose out on the opportunity to better internalize what he already is supposed to know. Consequently, through a learning perspective, AR should be used as an addition to speaking, not as a substitute.

Proposition 10: By guiding through digital markers instead of verbally explaining the necessary steps to be taken, the expert's potential to stimulate and integrate past learning experiences may be reduced.

Learning by doing

Yet, there are two reasons why the negative effects on learning may not be equally relevant with AR in the context of the PSE-group. First, the commitment and motivation of the people within the PSE-group can be regarded as high. As Roar noted: "There is a lot of commitment here [in this group]. There are many here who have found their right place in terms of interests ... they bring something more of themselves with them to work, they really do”. It was also stated that this commitment was an important factor when learning about the new technologies that Chemical Co dared to bet on. This is in line with Szulanski (1996) who found that persistence and motivation are important factors for individual’s retentive capacity and is therefore also crucial for learning. Second, the AR-experience in itself may be enough to motivate both the non-expert and the expert. One reason for this lies in the fact that AR provides an immersive, interactive and contextual learning experience for the users (Johnson et al., 2010). Thus, learning with AR is not like reading the words in a book. Instead, it is learning by directly experiencing the contents of the book for oneself. Jan remarked in this regard that: ”when someone is going to show me something technical that I need to learn … then I say, ‘can’t I do it myself, and then you explain it to me’ … you remember better, what you do yourself”. Consequently, by being automatically engaged in an activity in a rich AR environment, this will increase the motivation to learn. This is in line with Antonioli and colleagues (2014) who found that the use of AR in education demonstrated a higher degree of motivation and engagements in students.

Proposition 11: The AR experience enhances learning because it directly engages the user in activities in a motivating, contextual and interactive learning experience.

5.1.5 Technological aspects

Bandwidth problems

FaceTime is a video-based communication application available on iPhone’s. We have found that the team has experimented with this application on several occasions when there has been a demand for a visual representation of a problem. While it has been able to deliver some value, the team mentioned several of the application’s weaknesses. FaceTime is first and foremost an application designed to give a view of the face, not a view of the work. In other words, it is not an application specifically designed for remote assistance scenarios, in comparison to the AR application that was tested by the PSE-group in our experiment. Several of the engineers mentioned how using FaceTime had been less than ideal due to the image quality. This was also a complaint in regards to the AR application. Video-based calling requires extensive bandwidth. Furthermore, the PSE-group operates in an environment where a remote assistance scenario can take place “in a steel construction, or a concrete building” (Svein), where the coverage might be less than ideal. Therefore, an important factor to consider when evaluating whether using AR, or any video-based remote assistance application can be valuable, is whether or not the coverage allows for sufficient bandwidth to provide stable and clear transfer of video. Without a stable and clear transfer of video, the video stream is not continuous. Without continuous video, the expert may lose track of the situation as important information may be lost in the moments without video. When observing the experts, we experienced this to be an annoyance. Jan noted that it results in losing a bit of the journey: “you’re going from one point to the other and if you take away pieces of it then … in a way you get lost”. Still, the same problem yields for any remote assistance system which is not able to provide a continuous stream of communication. Whether the voice is unstable or the video is unstable, both can be equally annoying. This indicates that simultaneity and sequentiality are important factors in AR as a rich communication medium (Clark & Brennan, 1991), which also increases bandwidth requirements.

Proposition 12: Network infrastructure is a crucial prerequisite for any video- and AR-based remote assistance system because they require extensive bandwidth.

Hardware limitations and tracking inaccuracies

In all the cases we observed with AR, the most obvious weakness of the remote assistance tool was its size and shape. In the post-interviews, almost all the engineers agreed that having to hold an iPad with one hand, looking through it to perceive the digital markers placed by the expert, keeping track of reality, listening to the expert’s guidance, speaking and finally trying to actually solve the problem at the same time was a major difficulty. What we observed can be attributed to mental capacity being overloaded. This is in line with Porter and Heppelmann (2017) who states that “the ability to absorb and process information is limited by our mental capacity” (p. 5). In this state, we observed that the non-experts simply paid less attention to the iPad and its video streaming. Instead, their attention mostly defaulted back to solving the problem and using speech to communicate. For the expert trying to understand the situation through video, and further attempting to communicate through visual markers, this was an annoyance as the expert continuously had to remind the non-expert to adjust the camera to get a more accurate view of the situation. Svein described that this was an annoyance for the non-expert as well: “you look at the screen, and then you see that the iPad is not seeing the same thing, and then you have to adjust it … and all the time it was like that”. With a handheld AR system, the non-expert can only see the expert’s guidance through the device which has to be either mounted statically or held physically. This is less than ideal, as holding a large device to film and observe the world through, while troubleshooting is clearly resulting in overloading the mental capacity of the non-expert.

Proposition 13: Handheld AR systems have limited value in remote assistance uses cases because holding and focusing on an AR device, receiving guidance and performing actions in the real world at the same time leads to overloading mental capacity.

While the engineers generally agreed that having a shared visual interface was valuable, the AR capabilities in the software we used were not always found to be as valuable. Tracking inaccuracies were observed and mentioned by several of the engineers as a challenge with the software. This is in line with the limitations of AR found in the literature (Azuma, 1997; Billinghurst et al., 2015; Van Krevelen & Poelman, 2010). In the high-risk environment the PSE-group operates in, inaccuracies in marker placements can have severe consequences. Thus, this is an important limitation that must be overcome should AR markers be beneficial in high-risk environments.

Proposition 14: Tracking inaccuracies can cause digital markers to be placed, or be perceived to have been placed in a wrong place. This can cause confusion and possibly lead to hazardous situations should the markers be acted upon wrongly.

5.1.6 List of propositions

Table 6: List of propositions.

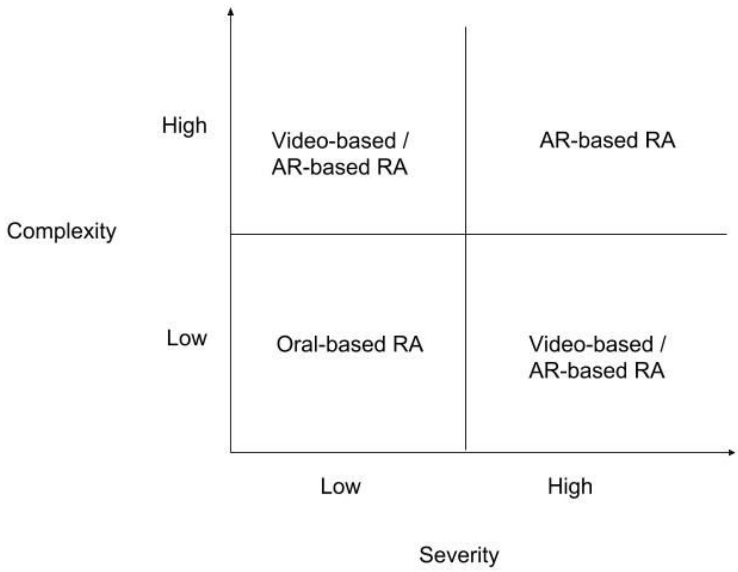
Proposition 1	A large gap in the competency level between an expert and a non-expert can be compensated by introducing video- or AR-based remote assistance.
Proposition 2	With AR it is possible to leverage the similarities in competency levels as this will enhance the communication within CoPs
Proposition 3	AR will make it easier to be aware of the other's competency level by increasing awareness and focusing attention on what is being communicated.
Proposition 4	Video- or AR-based remote assistance reduces the uncertainty in the expert's mental model.
Proposition 5	Video- or AR-based remote assistance can reduce cognitive load for the expert by providing a visual representation of reality.
Proposition 6	Imprecise speech when sharing knowledge explicitly may lead to a failure in establishing a sufficient common ground in communication.
Proposition 7	AR-based remote assistance has a larger potential to convey more tacit knowledge compared to oral-based remote assistance.
Proposition 8	With oral- and AR-based remote assistance, a lot of cognitive effort is spent on trying to establish a common ground in communication.
Proposition 9	AR-based remote assistance may lead to more passive non-expert's which can reduce the learning outcome from remote assistance scenarios.
Proposition 10	By guiding through digital markers instead of verbally explaining the necessary steps to be taken, the expert's potential to stimulate and integrate past learning experiences may be reduced.
Proposition 11	The AR experience enhances learning because it directly engages the user in activities in a motivating, contextual and interactive learning experience.
Proposition 12	Network infrastructure is a crucial prerequisite for any video- and AR-based remote assistance system because they require extensive bandwidth.

Proposition 13	Handheld AR systems have limited value in remote assistance uses cases because holding and focusing on an AR device, receiving guidance and performing actions in the real world at the same time leads to overloading mental capacity.
Proposition 14	Tracking inaccuracies can cause digital markers to be placed, or be perceived to have been placed in a wrong place. This can cause confusion and possibly lead to hazardous situations should the markers be acted upon wrongly.

5.1.7 Augmented Reality Value Model

Our findings indicate that AR is not always the most applicable tool to use in remote assistance scenarios. Furthermore, the analysis of our findings suggests that a shared visual interface without AR capabilities meets many of the PSE-groups needs in remote assistance scenarios. Thus, in certain scenarios, a video-based remote assistance application may be sufficient. Based on our analysis, we propose the following model as a tool for managers who seek to determine the appropriateness of AR for remote assistance use cases.

Figure 13: Model outlining remote assistance (RA) scenarios by severity and complexity



The Y-axis represents the complexity of a given problem in a remote assistance scenario, while the X-axis represents the severity of the situation as a consequence of the given problem. When a problem occurs, and the help of the PSE-group is requested, the complexity of the problem can vary significantly. For example, questions related to explicit knowledge or clarifications do not require advanced tools to answer. Furthermore, the severity of the situation can also vary. For example, a highly severe situation can be hazardous to the safety of employees on site. A richer medium to ensure the problem is solved as quickly as possible and with the highest precision possible can, therefore, be beneficial in such a situation. Another variable to consider in regard to the model in figure 12 is the frequency of the given problem. In some cases, high complexity problems with high severity happen very infrequently. Investing in an advanced remote assistance tool like AR might not be beneficial in such a case. While we found the AR application tested to be fairly intuitive, it is still considered an advanced digital tool that requires a certain amount of frequency to get used to. However, the notion of intuitiveness was in this study based on a group of technological savvy persons. Each case must be considered individually, and the purpose of the model is to serve as a guide, not as a truth. In accordance with social construction theory on communication media use, there are social factors that must be considered as well (Stephens & Sætre, 2004).

While social factors do not fit the scope of this model, the goal of the model is rather to consider the type of problems that can occur as an initial analysis of the appropriateness of a remote assistance technology. With a low complexity and a low severity, we found that the need for an advanced tool would be excessive. If the severity is in the very low end, we have found that the problems can often be postponed until the expert is available to fix the problem himself. Furthermore, when the complexity of the problem is low, oral communication is often sufficient. However, when the complexity is low, and the severity is high, then a more precise tool can be beneficial. While oral communication may be sufficient, the risk is higher when the severity is higher. Thus, with video the expert can verify that the non-expert is performing the correct action, reducing the uncertainty between the two actors. In most cases, video-based remote assistance is sufficient when the complexity is low, and the severity is high. However, some cases may require a higher degree of precision than others. For example, when the difference in competency level is large and an expert needs to guide a non-expert with very little knowledge on a given system, then AR may be applicable as it allows the expert to more precisely guide the non-expert with digital markers. The same yields for situations where the complexity is high and the severity is low. Some of these situations may require a high level of precision, making an AR-based remote assistance application beneficial over a strictly video-based application. Lastly, in the case of a highly complex problem and a highly severe situation, AR is most likely to be preferred as precision is critical.

5.2 Limitations

There are five main limitations in our study. The first limitation is in connection with the semi-structured characteristic of our interviews. A consequence of this approach was that we acted opportunistically and chose to follow up on emerging themes that the interviewees showed interest in. This may have led the interview into directions irrelevant to the purpose of our thesis, and thus important information may have been excluded from the results of this study. To safeguard against this, we prepared an interview guide with a few themes that we wanted to investigate. This allowed the interviewee to switch between the predefined themes on his own account, and it made it easier for us to understand if what was being said was relevant or not. For the most part, the interviewees were speaking within the boundaries of the themes without being obtrusively prompted by us to do so.

Second, there are limitations in generalizing based on a small sample. Because interviews and participant observations are both very time-consuming, this led to the selection of a relatively small sample. Thus, we only investigated within the PSE-group, not with any other department even though the PSE-group remotely assisted other departments as well. However, it should be noted that sampling in qualitative research is not for the purpose of choosing a group that represents the rest of the world, but to richly study the more embedded contextual and cultural influences (McCracken, 1988). Still, sampling was done in a purposive, theoretical and convenient manner (Teddlie & Yu, 2007). By drawing on past theoretical insights from both literature and our project report, this helped us choose a case study on remote assistance. Furthermore, we sampled purposively by considering relevant individual characteristics such as interest in technology and knowledge-intensive work. Lastly, we conveniently chose individuals who were most eager to take part in our study and those who were most accessible. Therefore, we believe that the generalization made in our results have relevance to other contexts with similar characteristics.

Third, as participant observers, there is a risk of becoming too involved and thus influencing our participants and coloring their interpretations of remote assistance with AR with our own. Thus, they may have given us some answers, or behaving in such a way as to respond to what we as observers consciously or unconsciously were seeking. This reduces the reliability of our results. We safeguarded against this by triangulating participant observation with semi-structured interviews which decreased subjective interpretations. Additionally, through the process of defamiliarization and familiarization, we increased our capacity of being able to spot and establish distance in both ourselves and the interviewees (McCracken, 1988). Thus, we were able to reduce disadvantages connected to researcher bias, response bias, and reflexivity (Yin, 2009).

Fourth, there are some limitations connected to the coding of data during the analysis process. We followed the coding strategy presented in section 3.3, where we iteratively reduced and refined the data into analytical categories. Even though we took actions to increase the reliability of the coded categories, such as triangulating with regards to different investigator perspectives, the analysis and coding process may be influenced by our subjective biases and interpretations. Consequently, this will reduce the replicability of the study as well as decrease the reliability of our results. We safeguarded against this by documenting the procedures as well as the gradual process of reflection and analysis (Kirk & Miller, 1986)

Lastly, we also observed some technological limitations due to the novelty or AR. The process system engineers had knowledge about some parts of the technology, but some parts were also unknown. This was because most of them were used to using iPads, which were used as AR hardware, but no one had tried AR software before. Due to limited resources, we only had time to give the engineers a brief introduction on how to use the different AR features before the cases started. This may have led to the engineers using the features that coincided with the iPad features they already had experience with instead of trying out the new AR features. Had they instead integrated the meaning of the different features, we may have been able to observe valuable data, such as how natural it feels to transfer between communicating by pointing to objects in the real world compared to pointing with a cursor through an iPad. Thus, because of a lack of training in the essential AR communication features, valuable data may have been excluded from our results and conclusions.

5.3 Future research

Our most important recommendation for future research is to use an AR device with a head-mounted display for studies on AR's impact on organizations. This device should have a transparent screen allowing the user to see both the real world and digital objects at the same time. Furthermore, for studies on remote assistance we recommend the system to include some form of image stabilization to give the expert in a remote assistance scenario a stable view of the situation. Using a handheld AR device was a major drawback in our study. With a handheld device, the non-expert struggled to film his viewpoint, while the expert struggled with understanding the situation based on the unstable and discontinuous video from the non-expert. This drawback removed a lot of focus from the actual process that we wanted to study. Thus, our results were distorted by this drawback. We believe using a head-mounted display would lead to a more unhindered remote assistance process, which would allow researchers to get a more detailed view of the effects of the technology. At the same time, studies with head-mounted displays would also uncover its inherent disadvantages. Thus, studies with both a head-mounted display and a handheld AR device are recommended as such studies could more clearly uncover the differences and applicability between these devices in certain scenarios.

While we believe a study with a head-mounted display would provide more insight into the effects of AR technology, we suggest future research to build upon the themes identified in our study. As our study was of the exploratory kind where our five themes emerged after analyzing the empirical data, we recommend future research continue to develop on these five themes. For example, a future study can use the five themes found in our study as a framework to gain a more detailed understanding of how each of these five themes affects knowledge sharing with AR in remote assistance scenarios. Still, we recommend future studies to remain open to other themes, as other contexts might uncover other areas of interests. As this study was limited to a single context, we suggest future research to study other contexts to see if our results are valid in those as well. Especially interesting would be other contexts that also include varying degrees of complexity and severity of problems to see if the model in this study can be generalized outside of its context. In addition to more studies on knowledge sharing with AR in remote assistance scenarios, we also recommend studying other use cases and other organizational topics.

AR is an emerging technology that we believe in the future will be as abundant as the smartphone has become in the last ten years. Furthermore, we believe the impact it will have on businesses will be even greater than that of the smartphone. Thus, we propose more research on the effects of AR on organizations in general. In our study, we have only studied AR's impact on knowledge sharing through the remote assistance use case. Future studies should consider other use cases as well to gain a more nuanced view of the impact of this technology. Specifically, we recommend future research to focus on a shared augmented reality where two people can view the same digital object, at the same place and at the same time. Many use cases present themselves in a shared augmented reality. For example, a study on knowledge sharing in a training use case could give more insights into the effects on cognition and knowledge sharing from contextualized digital objects.

6 CONCLUSION

In this master thesis, we set out to understand in what ways AR can be valuable for knowledge sharing in remote assistance scenarios. Through a qualitative, quasi-experimental study where we compared how a team of seven experts shared knowledge with and without AR we found that in some cases, AR can improve the knowledge sharing process, but not always. The study was performed in an industrial chemical production plant where the problems that arise can vary significantly by complexity, severity, and frequency. By ranging problems based on severity and complexity, we have found that AR may not always be necessary. Furthermore, as a single mistake can lead to severe consequences such as a costly shutdown of a factory, the environment can be characterized as high-risk. In this context, we found that the experts are dependant on sharing knowledge remotely both between each other and to other parts of the organization to fulfill their business purpose, which is to keep the chemical production running continuously at maximum capacity. Considering many organizations fail to share knowledge efficiently, we believe sharing knowledge remotely is of relevance to most organizations who wish to capitalize on their knowledge-based resources.

We have further found that the group under study face several challenges when sharing knowledge remotely with a mobile phone, or in other words, without AR. First, the competency levels between an expert and a non-expert can vary. Sharing knowledge with a non-expert who does not have the knowledge base to understand the instructions given by an expert is challenging through oral communication. Second, uncertainty exists in the construction of a mental model when an expert has to understand a situation based off of strictly oral communication and combine it with his own knowledge through memorization. This uncertainty can be a source of frustration and enough to terminate a remote assistance scenario in a high-risk environment. Third, sharing knowledge remotely requires a high level of precision in speech when constrained to oral communication. Furthermore, effective oral communication has been found to be dependant on sharing a similar language as well as culture. To succeed with sharing knowledge remotely, these challenges must be overcome.

To overcome some of these challenges, we have found that the team of experts has attempted to compensate for the limitations of oral communication by using a video-based communication application called FaceTime on their mobile phones. However, this application is primarily designed to give a view of the face, not a view of the work, which is most often the intention in remote assistance scenarios. Furthermore, poor video quality, a small sized screen and too many things to handle at once have led to the application being considered by the experts as less than ideal.

AR deals with these challenges by introducing digital markers that can be used as another layer of communication between an expert and a non-expert. First, we have found that AR is a rich medium that can reduce ambiguity and compensate for a large gap in competency levels by increasing the expert's ability to share more of his tacit knowledge. Second, there is less uncertainty about what the non-expert is experiencing when he is able to stream a live view of what he sees to the expert. This speeds up the process of constructing a mental model for the expert, allowing the problem-solving process to more quickly get to the core of the problem. Third, AR reduces the need for precision in speech and makes it easier to communicate as the non-expert and the expert sees the same thing, and speaks of the same visual representation. However, AR may inhibit learning by reducing the need for the non-expert to actively engage in the problem-solving process, but instead passively execute the expert's instructions. In addition, the expert needs to be aware that if he replaces his verbal explanations with digital markers, his potential to stimulate and integrate past learning experiences may be reduced.

These findings indicate that to achieve high-quality remote assistance, a lot of effort needs to be made to establish a common ground in communication, both prior to, and during the communication process. In oral-based remote assistance, a lot of effort went into remembering, visualizing, and being extremely precise. In this way, a common ground in communication was to some degree maintained by actively keeping a mental model of the problem in their minds. However, this quickly overloaded cognitive capacity. In AR-based remote assistance, a common ground was achieved automatically as the non-expert and expert's visual feed was constantly being shared. This allowed them to share a view of the work without having to spend a lot of cognitive load to precisely maintain a mental model of the problem in their minds. However, a handheld AR device did not sufficiently provide a stable common ground as effort had to be put into maintaining an alignment of visual fields. With a hand-held AR device, the non-experts cognitive capacity was overloaded as they had to use the device to film with one hand, troubleshoot the systems with the other hand, listen to the expert's guidance, and engage in problem-solving at the same time. This was also experienced as a frustration for the expert, as not having a continuous view of what the non-expert was experiencing could lead to important details being missed. Thus, a lot of effort was made to always align visual fields of the work which quickly overloaded cognitive capacity. Thus, we recommend future research to include a head-mounted display that would allow the non-expert to have his hands free and continuously provide the expert with a view of the work. In this way, a stable continuous common ground in communication can be established with as little effort as possible.

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APPENDIX A

A.1 Interview guide: Before AR

Themes (Grand Tour Questions)	Subthemes	Prompts
Remote assistance ● Can you take me through a recent situation where you experienced remote assistance?	● Technologies ○ FaceTime, mobile phone, SMS/e-mail, ScreenShare ● Pain points ○ Bandwidth and speed ○ Too much information ○ User interface ● View of technology ● View of visual communication	● What was good/bad? ○ What were the consequences? ○ How did you ductape painpoints? ● What was the difference between cooperating face-to-face and remotely with the use of technology? ● What were the difference between the technologies?
Knowledge sharing ● What kind of questions is originally asked?	● Type of knowledge ○ Data, information, knowledge (explicit or tacit)	● Are difficult questions asked? Why not? ● The knowledge that is shared, is it stored somewhere?
● Can you tell me about a situation where you felt that you were not understood?	● Motivation? Desire to learn? Shared goal? ● Do they share platform of knowledge? ● Tacit knowledge sharing	● What were the reasons? What were the barriers? ● What is required of the cooperation/communication?
Context ● Can you describe your working environment in the department? ● How do you share knowledge in your department? ● What factors influences how well the cooperation and knowledge sharing works in your department?	● Socal acceptance ● Shared language ● Integration ● Community of Practice ● Works on projects together	● What distinguishes your expertise from the other's expertise? ● Who is involved? More/less interested? What is the difference between these persons? ● What happens with the knowledge after it is shared? Is it integrated into a larger context/culture? Are more people involved? ● How would you describe the culture in your department?

		• What kind of activities and engagements is centered around the different experts in your department?
AR • What is your first thoughts when I say Augmented Reality?	• Knowledge sharing	• Advantages/disadvantages for cooperation?

A.2 Interview guide: After AR

Themes (Grand Tour Questions)	Subthemes	Prompts
Remote assistance with Augmented Reality • How was your experience with Augmented Reality? • If you had this technology available right now, what would you use it for?	• Comparing before/after AR ○ FaceTime, mobile phone, SMS/e-mail, ScreenShare vs AR • Pain points ○ Speed and bandwidth ○ Too much information ○ User interface ○ Hardware ○ Software • View of technology • View of visual communication	• What surprised you? • What disappointed you? • What was good/bad? • What did you miss with this technology? • Do you see any opportunities/pitfalls? • What was the difference between cooperating face-to-face and remotely with the use of AR?
Knowledge sharing • How would you describe the cooperation and communication with AR remote assistance? • How would you describe the learning outcomes with the use of AR?	• Type of knowledge ○ Data, information, knowledge (explicit or tacit) • Information visualization and external cognition • Learning • Easier/harder to convey/explain/visualize deeper tacit understanding	• Was there anything that was easier/harder to explain with AR compared to without AR? • Was there anything that was easier to understand with AR compared to without AR? • How would you say the visual markers affected you (arrows, highlights, live cursor) • What do you think is required to communicate

		with AR?
Context • What kind of reactions do you think your department would have if you had implemented remote assistance with AR now?	• Values, attitudes, beliefs, norms, expectations, status • Social acceptance • Openness and motivation? Desire to learn?	• Your reaction vs department reaction • Do you often implement new technologies? • How does your department handle change?