UNIVERSITY OF GOTHENBURG

DEPARTMENT OF EDUCATION, COMMUNICATION & LEARNING

AUGMENTED REALITY FOR MAINTENANCE AND REPAIR TECHNICIANS

Possibilities for Training and Service

Liesl Aparicio

Thesis:	30 higher education credits
Program and/or course:	International Master's Programme in IT & Learning
Level:	Second Cycle
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Supervisor:	Jonas Ivarsson
Examiner:	Markus Nivala
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Abstract

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Purpose: The purpose of this thesis is to first explore the current training and service setting of maintenance and repair technicians at a medtech company, and secondly to discuss the opportunities and challenges of using augmented reality in training and service. It will serve as the beginning analysis phase of design-based research. The position this research takes is not driven by seeking applications for the technology of AR, but rather it is concerned with the issues and goals of trainers situated in a maintenance and repair setting, and how AR could be employed based on those issues and goals.

Theory: This thesis is the analysis phase of design-based research which is a series of approaches that have the intent of producing new theories, artifacts, and practices that can potentially impact learning and teaching in naturalistic settings.

Method: Two rounds of unstructured interviews in a group setting were conducted. These were separated in time by a phase of research and testing of different AR solutions reflecting the needs expressed in the initial interview. This information was then presented to the trainers as stimulus material to provoke and sustain discussion for the second interview. Both interviews were recorded, transcribed, and finally thematic analysis was used to produce a systematic recording of the themes and issues addressed in the interviews.

Results: The trainers reported that their main goals are to create learning environments where the technicians can make mistakes, be confident and receive practical hands-on training, which will lead to a more standardized service throughout the company. They also would like to create guides and easily accessible information for the technicians to use after training while working on-site. The trainers thought AR-based training and guidance applications could offer several opportunities such as displaying learning material in a manner that allows for more hands-on training, the ability to re-create machines or parts that are difficult in which to gain access, and be a helpful resource for on-site work. Their main concerns were how to introduce the technology to the technicians, and the time and energy needed to create these applications. In conclusion, this study shows how each AR display can be employed in different learning phases and service, and that AR-based training and guidance applications offer many useful and beneficial features that can be developed at this medtech company and other settings as well.

Foreword

I would like to thank my fellow classmates and everyone who encouraged and supported me while I worked on this thesis. Special thanks to Camilla Olsson for your assistance in accessing articles, Jonathan Westin for taking the time to teach me how to create AR applications and sharing your knowledge in this field, Thomas Hillman for your advice during our peer review session, and especially my supervisor Jonas Ivarsson for your quick responses, guidance, and support in organizing this study.

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List of Abbreviations

AR Augmented Reality

VR Virtual Reality

CV Computer Vision

HMD Head Mounted Device

HHD Handheld Device

SAR Spatial Augmented Reality

P&I Piping and Instrumentation

VAC Vergence-Accommodation Conflict

1 Introduction

Only over the past decade has there been enough work to refer to Augmented Reality (AR) as a research field, even though the concept has generally been dated back to Ivan Sutherland's work in 1986, “A head-mounted three dimensional display” (Azuma et al., 2001). The objective of Sutherland’s project was to surround the user with a perspective image that changed as they moved by placing suitable two-dimensional images on the user’s retinas, creating the illusion that they were seeing a three-dimensional object.

Augmented reality is generally defined as a combination of the real world with computer generated elements, and can even appear to remove real world elements by adding virtual ones (Azuma et al., 2001). The addition or removal of information displayed in the visualized real scene can magnify the user’s visual experience, and can potentially increase the user’s comprehension of their physical environment (Gomes et al., 2017). AR is related to the concept of virtual reality (VR) in that both technologies can bring about an interactive experience, but the difference is that AR aims to supplement the real world rather than creating an entirely artificial one (Höllerer & Feiner, 2004). It has also been considered a subfield of mixed reality, which is a broader concept that also includes simulations usually taking place in a virtual domain and not in the real world (Höllerer & Feiner, 2004).

AR relies on visual features that are naturally present in the real world by using computer vision (CV), which aims to take geometrical, topological, or physical information from the image or objects which are present, and it is this information that can allow the recognition of object classification or patterns (Gomes et al., 2017). The digital images or objects transmit information, such as color and light intensity, which allow image analysis through image processing (Gomes et al., 2017).

The process of tracking and registration is used to evaluate the position of objects in order to align virtual content with physical objects in the real world (Chatzopoulos et al., 2017). There are two methods of tracking and registration: sensor-based, which uses inertial and electromagnetic fields, and radio and ultrasonic waves to calculate and measure objects positional information, and vision-based, which uses point correspondent relationships of markers and features from images and videos (Chatzopoulos, Bermejo, Huang, & Hui, 2017).

AR can be employed in a variety of applications. In medicine it been used to increase precision in laparoscopic procedures, to highlight hidden structures, and to project pre-scans of MRI, CT or ultrasound data onto patients aiding the surgeon’s orientation and surgical approach without requiring the surgeon to take their eyes off the surgical field (Pelargos et.al, 2017). AR can give users public or private information by annotating objects and environments using notes or labels (Azuma, 1997). In construction architects use AR to see pipes and electrical lines inside buildings (Azuma, 1997). Using AR for car navigation has been well studied offering interface solutions that attempt to overcome issues such as spatial cognition ability, the ability to accurately represent a spatial environment mentally, and divided attention (Jose, Lee, & Billinghurst, 2016; Kim, & Dey, 2009). The entertainment industry uses AR to cut costs by creating virtual sets instead of building expensive physical ones (Azuma, 1997). The military has used AR for years to superimpose vector graphics, navigation and targets on to pilot’s field of vision (Azuma, 1997). Furthermore, it can assist in the assembly, maintenance, and repair of complex machines by making instructions easier to understand using 3D images with a step by step procedure displayed on the actual machine (Azuma, 1997).

It is this last example, the maintenance and repair of machines and the training of these procedures, which is the particular interest and focus of this thesis. Maintenance can be defined as the actions which aim to restore any functionality of a product within its lifecycle (Palmarini et al., 2018). Some types of maintenance operations that employ augmented reality are disassembly and assembly, repair, inspection and diagnosis, and training (Palmarini et al., 2018).

Currently, human labor operations are still relied on in the manufacturing field, and improving the accuracy and efficiency of technician's who engage in this type of work is significant because it directly affects the product quality (Yin et al., 2014). Furthermore, maintenance efficiency is a key factor in reducing cost, and as industrial systems become more and more complex it is increasingly difficult to find operators with the necessary skills to perform these complex tasks, or they need longer training periods to be autonomous (Havard et al., 2016).

AR having the capability to overlay real world and virtual content in real time is a major topic in the research and work in industrial maintenance (Havard et al., 2016). Furthermore, studies of AR in education have significantly increased since 2013 (Chen, Liu, Cheng, & Huang, 2017). Most studies report that AR in educational settings lead to better learning performance and motivation, that it supplies authenticity and interaction, deeper student engagement, enjoyment, and overall positive attitudes towards AR (Chen et. al, 2017).

Industrial companies demand for applications that use AR technology has so far only been used in a limited form, due to the high precision required to perform these types of tasks, and the complexity of object tracking and detection processes needed for these environments (Gomes et al., 2017).

Given the many uses of AR, the need for maintenance efficiency, and the increasing complexity of tasks in the maintenance and repair field resulting in longer training periods the specific interest of this thesis is to consider and explore how AR could be applied in the training and service of maintenance and repair technicians at a medtech company.

2 Literature Review

To give an overview of previous studies done using AR for maintenance and repair procedures a systematic literature review was conducted for this thesis. This review will provide summaries of the different displays used, advantage and disadvantages of those devices, user feedback, authoring of AR documentation, and AR in training.

The databases used were Scopus, Web of Science, and ACM digital library. The initial search terms were "augmented reality", "maintenance", and "repair". The search returned 185 documents. The key words "instruction", and "procedure" were added which narrowed the results to 122 documents. The final search term "training" was added to narrow the results down to 32 documents. These terms were chosen because they narrow the scope of this literature review, give different perspectives on how augmented reality is used in a maintenance and repair, and give insights that will directly influence this thesis. Documents that were included in this literature review were ones that were conducted in the last 10 years, that included the aforementioned search terms, were in English, and that were situated in a maintenance setting or context. Mendeley paper management was used to import, organize and reference the literature. After removing the duplicate documents from the databases, and applying the above mentioned criteria 20 documents remained.

2.1 Different Displays

The term "display" as used in this thesis refers to three different principles of how images are shown to the user: on a separate device, directly on physical objects, or in between the eye and the real world. This section discusses the principle on which a specific electronic device visually presents images.

There were three main displays used within the literature: Head Mounted Devices (HMD), Handheld Devices (HHD) and Spatial Augmented Reality Devices (SAR). 11 articles used HMDs, ten articles used HHDs, and seven of those used a combination of both. Four articles used SAR and one of those articles used a combination of HMDs and SAR. Two articles could have been applied to any or all of the three devices listed.

HMDs, also referred to as a "wearable" or "AR glasses", are worn by the user, and are the most used in maintenance operation studies (Palmarini et al., 2018). To superimpose graphics onto the user's view of the real world, there are two types of technologies that exist: See-through and Video Display. See-through displays are based on semi-transparent mirrors that allow the user to "see through" while at the same time reflecting computer generated images directly into their eyes (Palmarini et al., 2018). Video displays captures the real world and overlay the computer generated AR objects through a small display in front of the user's eyes (Palmarini et al., 2018). See-through HMDs allow the virtual objects and real world to be perceived more naturally, but there is less control when it comes to synchronizing the virtual image with the scene (Carmigniani et al., 2011). Consequently, the user can perceive the time lag and image processing which makes the virtual images look detached, jittery and unstable (Carmigniani et al., 2011). Video display HMDs have more control over the visual result because the augmented view is already composed by the computer, and the timing of the real world is achieved by synchronizing the virtual image before displaying it (Carmigniani et al., 2011). However, this technology requires the user to wear two cameras, one to provide the real part of the scene and the other to provide the virtual objects resulting in unmatched resolution (Carmigniani et al., 2011).

HHDs are small computing devices that the user can hold in their hand, such as smartphones, palmtop computers, or tablets (Carmigniani et al., 2011). They also, use video-see through techniques that overlay graphics in the real world using cameras to capture the live video and blend it with virtual information before displaying it on the screen (Chatzopoulos et al., 2017).

SAR also referred to as "projection based AR" separates the technology from the user and is integrated into the environment (Carmigniani et al., 2011). The virtual content is displayed on real object surfaces, such as walls, paper, or a human palm, rather than displaying mixed content on a specific interface (Chatzopoulos, Bermejo, Huang, & Hui, 2017).

2.2 Advantages and Disadvantages of Different Displays

Any of the three displays will have some similar disadvantages that presently exist. They all need a power source, and since many AR systems rely on the internet to provide data in order to display the digital scene there could be issues of connectivity (Kapetanovic & Fazlmmashhadi, 2012). Especially when considering mobile devices because AR applications require long-time simultaneous cooperation between camera capturing, GPS retrieving and internet connections, but the batteries in mobile devices are designed to be sustainable only for common functions used in intervals like picture capturing and internet access (Chatzopoulos et al., 2017) This would need to be improved in order to sustain the heavy computations required for AR applications (Chatzopoulos et al., 2017).

See-through and video see-through displays are usually unsuited for outdoor use, because they are dependent on lighting conditions (Dini & Mura, 2015). For example, in see-through displays a major problem is that they block the amount of light generated from the real world causing the background environment in the display to become too bright making it difficult to distinguish virtual content from the real world (Chatzopoulos et al., 2017). Furthermore, it is challenging to implement AR systems outdoors because vision-based tracking methods require artificial markers to be registered beforehand, and sensor-based methods performance of real-time registration cannot achieve exact object tracking because of the systemic error produced when using only global positioning system and inertial measurement units (Huang, Sun, & Li, 2016).

This is significant because accurate position and orientation tracking is required in order to trick the human sense into believing that a computer-generated object or information coexists with the real environment (Carmigniani et al., 2011). Many high accurate tracking approaches available in CV fields cannot be directly used on mobile devices, again, due to their limited computing capabilities (Chatzopoulos et al., 2017). Sensor-based tracking methods suffer from shielding, noise and interference, and vision-based tracking suffers from view occlusion, clutter and large variation in environment conditions. (Chatzopoulos et al., 2017). As a consequence, these issues with display solutions still do not suit strict industrial constraints about ergonomics, training of operators, and reliability (Uva et al., 2018).

However, as critical as these initial disadvantages may sound, the examples above discuss scenarios where precise tracking is needed, which may not always be required. Deciding which method to use, vision-based or sensor-based, depends on the accuracy and granularity needed for the application (Chatzopoulos et al., 2017). For example, some tracking errors can be acceptable if only the rough outlines of a building need to be annotated, whereas more accurate tracking would be required to pinpoint a particular window on that building (Chatzopoulos et al., 2017).

It is important to keep in mind that these AR support systems are still in the early stages, and it is believed that in the future companies will make better use of them (Uva et al., 2018). The following sections will use some examples from the literature to describe some of these disadvantages more in depth, but also the advantages of each display in the maintenance and repair field.

2.2.1 Head Mounted Devices

Beginning with HMDs, the biggest advantages found in the literature is that they allow the user to be hands free, and that they are mobile meaning they could be used at many different working sites. When compared to other types of instructional displays they do reduce task completion times, and perform the same or slightly better when it comes to reducing errors, but it seems the current technological deficiencies of HMDs still outweigh the benefits this type of display could offer.

Havard et al. (2016) conducted a case study that compared the maintenance efficiency between paper, video, AR tablet and AR Smart Glasses Vuzix M100. They found that participants who used the HMD performed maintenance tasks faster, although they admit not significantly better, than with the HHD, video and paper. When it came to errors, they found that the HMD ranked second behind video, followed by the HHD and paper

Büttner, Funk, Sand, & Röcker (2016) compared HMD, Vuzix STAR 1200 glasses, against SAR projection based display using paper instruction as a base line. They found that both SAR and paper instructions showed significantly faster task completion times and lower error rates than HMDs. They argued that the technical state of HMDs simply are not ready as an assistive system in assembly tasks. They even conducted the study again using Epson Moverio BT-200 glasses to help ensure their study was not influenced purely by the Vuzix STAR 1200 glasses, but interestingly they found the results to be the same. They point to three main reasons for this. First, the displays in HMDs have a low brightness, and a few of their participants could not see the instructions, and ultimately were forced to remove their glasses in order to complete the task. Second, the glasses restricted the participant's vision. They found that the users had difficulty changing their focus between the instructions in the top right corner of the displays to the task in front of them. Thirdly, they believe this technology may prove to be difficult to apply to a large market since, currently, they are not made for individuals who wear corrective glasses. Furthermore, they do not take into account the distance between the user's eyes and the displays which can be distracting and uncomfortable. They also mention the battery life being insufficient to last even one shift of their participants work day.

Dini & Mura (2015) mention many of these same issues in their literature review. They found that HDMs have a small field of view and limit peripheral visibility, which they indicate could be a safety issue for workers. They discuss how HMDs, and also HHDs, are greatly dependent on lighting conditions, and are usually unsuited for outdoors or low lit environments.

Another major issue concerning stereoscopic 3D displays, is a well-known problem called vergence-accommodation conflict (VAC) (Jang et al., 2017). Binocular or stereo displays, which allow objects to be displayed with the correct left/right eye disparity, show the computer generated graphic at the same apparent depth requiring the user's eyes to accommodate at that particular distance causing VAC (Höllerer & Feiner, 2004). The eyes are forced to converge at different depths, and the result is a conflict in the expected depths of visual stimuli which causes blurred or double vision and visual discomfort (Shibata et al., 2011; Carnegie & Rhee, 2015). However, higher performance HMDs are expected in short time since many hi-tech leaders (i.e. Google, Sony and Microsoft, etc.), are making great efforts to develop better HMDs (Fiorentino et al., 2016).

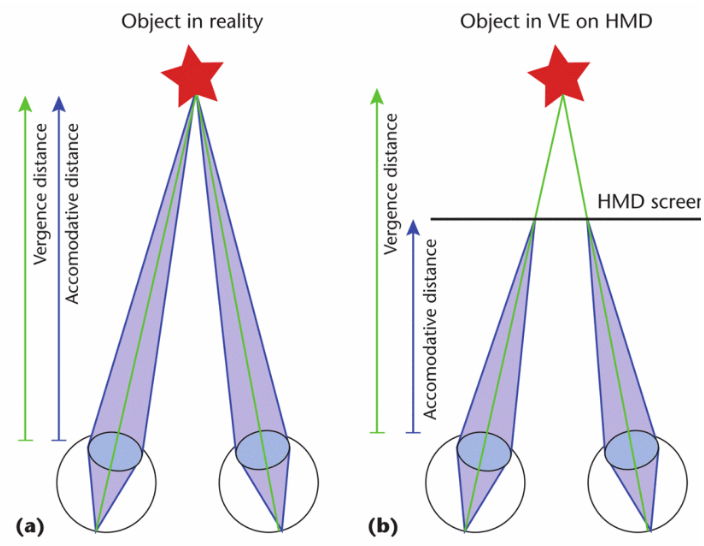

Figure 1. Comparison of accommodative distance with and without HMD. Adapted from "Reducing visual discomfort with HMDs using dynamic depth of field." By K. Carnegie, and T. Rhee, 2015, IEEE computer graphics and applications, 35(5), 34-41.

2.2.2 Hand Held Devices

Moving on to the next display mentioned in the literature, HHDs are valuable in that they can include devices that are affordable and mobile, like smart phones and tablets, and are more powerful than HMDs. They, however, as mentioned suffer from lighting condition just like HMDs, and they force the user to use their hands to operate which is not ideal in maintenance and repair work.

Looking again at the work of Havard et al. (2016), they selected a tablet as a HHD for their study because they believed that tablets would offer an intuitive interface, and a wide enough screen size for users. They found that participants performed tasks faster with the HHD than with paper and video instruction, but it only outperformed paper when it came to error rates.

Engelke et al. (2015) present in their work a concept for building an AR-enhanced support system based on abstract maintenance task descriptions. They sought to convert already existing paper manual descriptions to more emerging ones, making use of electronic devices and AR functionality. They said they chose a tablet for their work because they felt they are "ready-to-use", powerful, and affordable. They created 3 different interfaces that users could choose between: AR mode, VR, mode, and 2D mode. AR mode emphasized areas of interest by highlighting or outlining parts of the machine. VR mode showed a 3D model of the machine along with annotations. Finally, the 2D mode showed a traditional sketch of the machine.

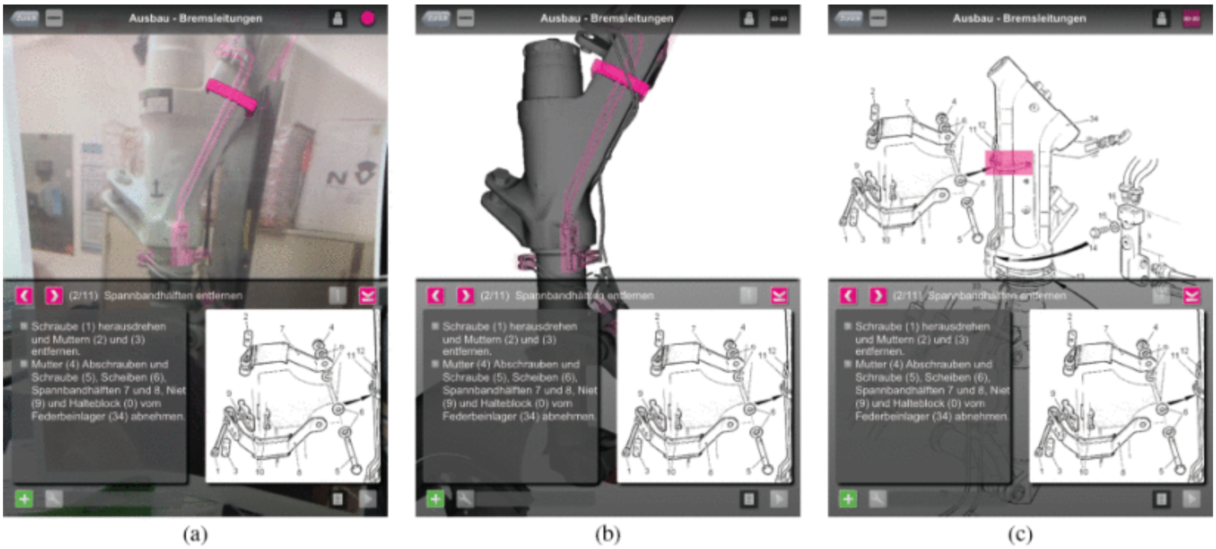

Figure 2. Three Interfaces. Adapted from "Content first: a concept for industrial augmented reality maintenance applications using mobile devices." By Engelke et al., 2015, Proceedings of the 6th ACM Multimedia Systems Conference (MMSys '15). ACM, New York, NY, USA, 105-111.

They found that most participants began their work using the sketch mode and slowly moved to using the AR and VR mode as they became more comfortable with the system. While their study mostly focused on authoring techniques, their final conclusions are particularly significant about the use of HHDs in general. They found that even though participants had to switch between the various modes and between holding and putting the device aside they did not lose the contextual idea of the task they were executing. The authors also argue that this type of application can be transferred to other contexts besides industrial maintenance considering tablets are easily accessible for people today.

2.2.3 Spatial Augmented Reality

The final display, SAR, has some advantageous mentioned in the literature over HMDs and HHDs in that projectors offer brightness and do not suffer from the same lighting issues, they are hands free like HMDs, and reduce error rates.

They can be used by multiple users simultaneously, are much easier for the user's eyes, and reduce motion sickness and distraction (Kapetanovic & Fazlmmashhadi, 2012). This distraction phenomena, also called tunnel-vision or tunnel attention, occurs when the user is distracted with unnecessary information that prevents them from noticing important cues in the environment, which occurs more with poorly designed interfaces in HMDs and HHDs (Kapetanovic & Fazlmmashhadi, 2012). Other advantages include self-calibration, infinite focal length, low power usage, and high brightness (Chatzopoulos et al., 2017).

A disadvantage when using SAR is that the projected images can become distorted based on the surface on which they are projected, and users could misunderstand the instructions (Uva et al., 2018). Perhaps their biggest disadvantage, however, is that they are not mobile limiting them to only certain applications where the workers are stationary like car maintenance, assembly lines, or workbenches.

Uva et al. (2018) had engineer students perform a small maintenance procedure of a Honda CBR 600 motorbike engine to evaluate the effectiveness of SAR in comparison with a paper manual conveying technical instructions. They measured task time completion and error rates, and gathered user feedback with a small questionnaire. They found that SAR technology greatly reduced error rates when compared to paper, but that it did not appear to offer an advantage when it came to task time completion. Moreover, they found that users accepted the technology finding it overall easy to use, intuitive, and useful. Another insight their research offered was that SAR was more beneficial when it came to difficult tasks, which they define as increasing when the mental capacity investment increases as a necessity to achieve the required level of performance.

Fiorentino, Radkowski, Boccaccio, & Uva (2016) tested an interaction method using a projector which displayed virtual objects and virtual motion buttons during an automotive maintenance procedure. They wanted to test if the users could trigger maintenance instructions by moving their hands in regions sensitive to motion speed and direction while holding tools, wearing gloves or with additional movement in the background or foreground. They did this by using a tracking camera, an interaction camera, a projector and a monitor.

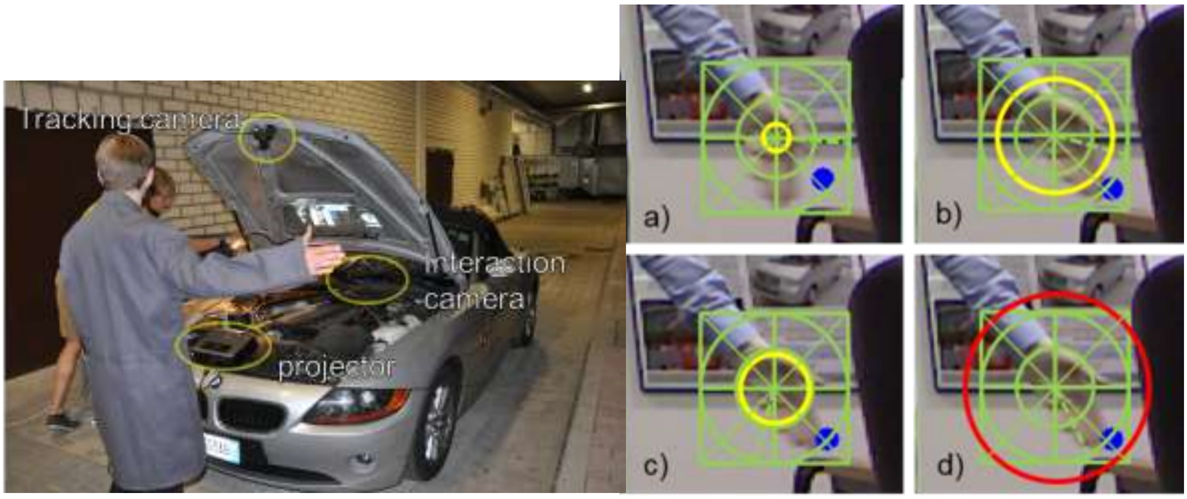

Figure 3. Automotive Case Study. Adapted from "Magic Mirror Interface for Augmented Reality Maintenance: An Automotive Case Study." By M. Fiorentino, R. Boccaccio, and A.E. Uva, 2016, Proceedings of the International Working Conference on Advanced Visual Interfaces (AVI '16), Paolo Buono, Rosa Lanzilotti, and Maristella Matera (Eds.).

Overall, the results were positive in that the users were successfully able to interact with the virtual buttons and complete the maintenance procedure. They also found that movement behind the user did not affect the set up. The do mention that the results were less successful when the user was holding tools and trying to interact with the virtual buttons and that if the gestures were too fast they would not trigger the virtual buttons. They conclude that adding more computational power and refining the algorithm would help alleviate these issues.

2.2.4 Different Displays Summary

While there is no overall best solution to many of the challenging areas that have been discussed in the above section of this thesis new research results are constantly opening new avenues of exploration, and a developer planning to deploy AR technology for a specific task needs to make design decisions that optimize the chosen AR display's performance based on careful task analysis (Höllerer & Feiner, 2004). After reviewing all of this information about different the devices used in AR applications, it seems to follow that the type of display that is most effective depends entirely on the type or task or work being done. HHDs and SAR are more robust, powerful and especially in the case of SAR have better display capabilities than HMDs, but they are not as well suited for all types of work that require users to use their hands or move to different working sites and conditions. While these displays could be useful in some applications there seems to still remain some technological issues that need to be resolved before they can be used in more maintenance and repair work.

Despite some of the current technical disadvantages of AR the literature generally agrees that AR tends to be the same or better than traditional instruction manuals, such as paper or video, when it comes to task time completion and error rates. The literature also seems generally positive towards the continuing work and development of AR for maintenance and repair work.

2.3 User Feedback

The next important question addressed in the literature is what the users' opinions are towards the technology. Of the 20 articles reviewed for this thesis seven recorded feedback from the users of their study, usually in the form of interviews, observations or questionnaires.

Aromaa, Aaltonen, Kaasinen, Elo, & Parkkinen (2016) used questionnaires, interviews and observation to determine the user experience and usefulness of two technologies to support knowledge sharing in maintenance. After conducting two case studies, the first using Vuzix m100 smart glasses and other "wearables" which consisted of an android smartphone, Sony smartwatch, and the second using an iPad air tablet, they reported that the technicians were mostly positive towards the use of the technologies in their work.

Figure 4. Wearable System. Adapted from "Use of wearable and augmented reality technologies in industrial maintenance work." By S. Aromaa, L. Aaltonen, E. Kaasinen, J. Elo, and I. Parkkinen, 2016, Proceedings of the 20th International Academic Mindtrek Conference (AcademicMindtrek '16).

In both cases the technicians thought the systems were easy to learn, easy to understand, and for the most part could ease their work. The technicians in the second case study, who used the tablet thought the AR instructions would be better than paper since it would be easier to update and there was less of a language barrier with the instructions being more visual. There were also, however, some difficulties with the technology that were uncovered as well. In the first case study, it was difficult for the technicians to operate so many devices at once, and they often confused the order of the procedure on the devices. The devices also did not entirely suit the working conditions. The smartwatch would slide under the technicians' working gloves, the smart glasses would fall off if they removed their helmet, and in both cases the technicians continually needed to remove their gloves to operate the smartphone or tablet slowing down their work. Interestingly, however, the technicians said they did not mind stopping their work to hold the tablet. In the second case study the technicians thought there would be some resistance from their colleagues, and that the technology was not robust enough for their working conditions.

Funk et al. (2017) also recorded a mixture of positive and negative results from interviews in their study which used SAR, with projectors, to display in situ instructions comparing performance of trained and untrained workers. The workers stated that once they learned the system they found it relaxing and that it supported their work. They also felt, however, that it could be irritating and that they would not like to use it every day, but that it would be useful when learning new tasks.

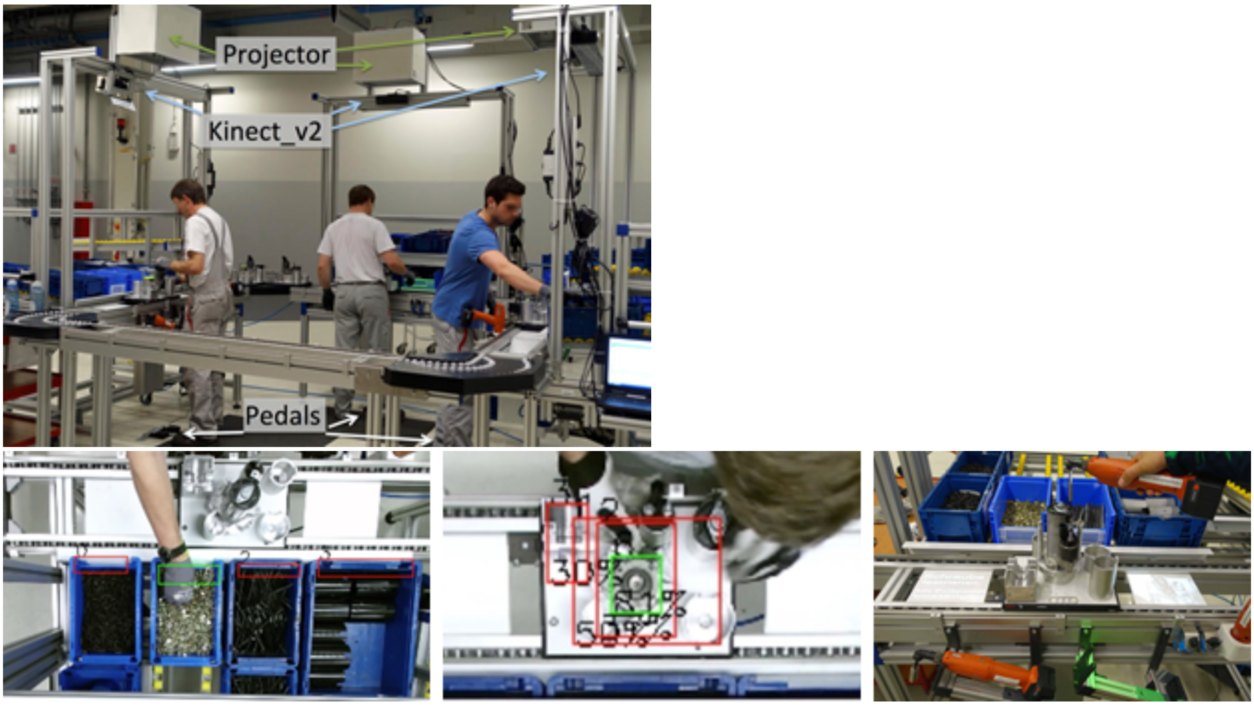

Figure 5. SAR in situ Instructions. Adapted from "Working with Augmented Reality?: A Long-Term Analysis of In-Situ Instructions at the Assembly Workplace." By Funk et al., 2017, Proceedings of the 10th International Conference on PErvasive Technologies Related to Assistive Environments (PETRA '17).

The technicians in Fiorentino, Radkowski, Boccaccio, & Uva (2016), which, as mentioned earlier, tested an interaction method using a projector that displayed virtual objects and virtual motion buttons during an automotive maintenance procedure, were concerned that there might need to be an alternative to the fiducial markers attached to some of the elements. They felt they could easily be cluttered by dirt and in a real scenario would not work with the projection system. They found the virtual buttons very useful, though, and wanted them to be integrated in the projection display instead of the side monitor. The authors also found it significant that none of the users mentioned fatigue, although they thought this could also be attributed to the limited duration of the test and the simplicity of the task.

This feedback in the literature shows that users seem to have mixed feelings about using AR in their work, and that most of the negative comments tend to be about the device's shortcomings or the way in which the AR instructions are presented. As the technology develops perhaps the user feedback will change as well.

2.4 Authoring of AR

Creating instructions or manuals does not only rely on the technology used to display it, but also the way it which it is designed and authored. Gattullo, Uva, Fiorentino, Scurati, & Ferrise (2017) mentions the lack of guidelines technical writers have to follow, and that the technical documentation for AR visualization is seldom addressed in the literature. They said the lack of an authoring standard in the creation of technical documentation seems to have caused a tendency that the conversion of traditional manual instructions are simply converted to a digital format without truly utilizing the visual capabilities that AR can offer. They suggest that a better solution would be to use a more augmented image approach and reduce the text information, which they say occludes reality, and rethink the documentation and the creation of all the contents from scratch. They, also discussed a method to reduce text in technical documentations using the rules of Controlled Natural Languages, which they define as a subset of natural language that restricts vocabulary and grammar in order to reduce ambiguity and complexity. They divided technical instructions into two categories: instructions that can be presented with graphic symbols and instructions that should use text.

Relating to graphic symbols or images Webel et al., (2012) discusses using Adaptive visual Aids instead of the traditional Augmented Reality overlays, such as detailed 3D models or animations, which tend to suffer from the current technologies tracking inaccuracies. They demonstrated a strong guidance level and a soft guidance level as a way to work around some of the current technologies tracking issues.

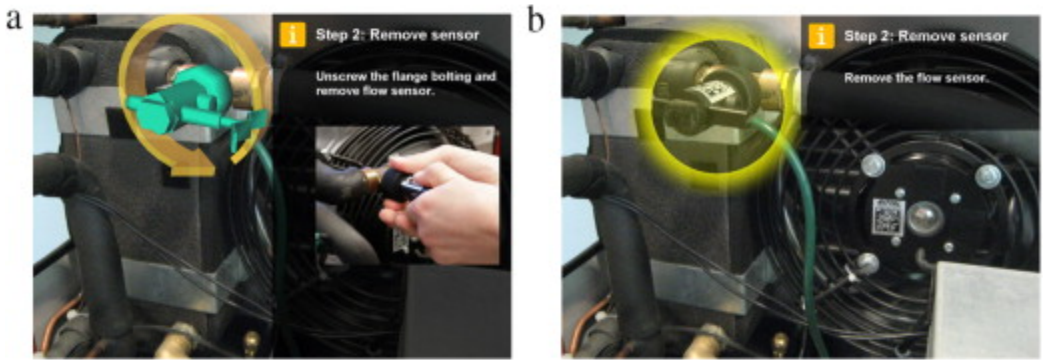

Figure 6. Hard (a) and Soft Guidance (b). Adapted from "An augmented reality training platform for assembly and maintenance skills." By Webel et al., 2012, Robotics and Autonomous Systems, Robotics and Autonomous Systems.

Engelke et al., (2015) agrees that practical authoring solutions are critical and in their work they try to offer a general customizable application framework to support technicians in their daily tasks. They evaluated 30 different instruction handbooks for technical machines and the following elements as a usual part of workflow descriptions:

- A list of tasks that are described within the document
- Technical overview as a sketch, usually annotated with numbers and a legend with corresponding descriptions
- An abstract description of the task
- A detailed view that usually emphasizes or indicates a certain detail within the overview
- Hints, reminders and attention signs (Danger, Warning, Caution) with descriptions
- Links to other media (e.g. video URL)
- Annotations or corrections of users that have performed the task

As a result, they present an application development system based on web-standards such as HTML, CSS and X3D, which has already been briefly described in the HHDs advantageous section of this thesis.

2.5 Training

Eight of the articles discussed the use of AR in training, either as an aid, manual or step by step guide usually while the user was on the job. Two articles went into more detail of the advantages and design properties of using AR specifically for training and learning. Webel et al. (2012) developed and tested a platform for multimodal based training of maintenance and assembly skills. They studied two groups to analyze the efficiency of the training platform and to compare the performance of the trainees. The task performed by each group was to assemble an electro-mechanical actuator. The first group performed the task while watching an instructional video that showed the task steps, and the second group performed the task while using the AR platform. The AR platform consisted of a tablet which used Adaptive visual Aids, as already described in the previous chapter, and a vibrotactile bracelet which gave the technician's hints for rotational or translational movements or stimuli for presenting error feedback.

Figure 7. Technician wearing a Vibrotactile Bracelet. Adapted from "An augmented reality training platform for assembly and maintenance skills." By Webel et al., 2012, Robotics and Autonomous Systems, Robotics and Autonomous Systems.

In the end, they found that after one training session the skill level of the technicians who trained with the AR platform was higher than those who used the instructional video. The group that used the AR platform made less errors and achieved better task completion times. The vibrotactile feedback was thought to have a high potential for skill training enhancement, and that overall AR has the potential to be a useful technology for maintenance and assembly training.

Yin, Gu, Qui, & Fan (2014) created an SAR training guide that developed and tested a VR and AR-based manual operation instruction system. The system consisted of a desktop computer, and a Logitech HD Webcam C270 camera. Basically, the user begins the step by step process using the instructions on the desktop computer, and a 3D model of a machine part, which is projected on a fiducial marker, which they referred to as the dynamic locator. Then a virtual animated hand tutor shows the required actions for each step using basic gestures such as idle, grab and carry, and a PC that shows the step by step instructions. The user can then imitate the hand gestures and interact with the 3D model.

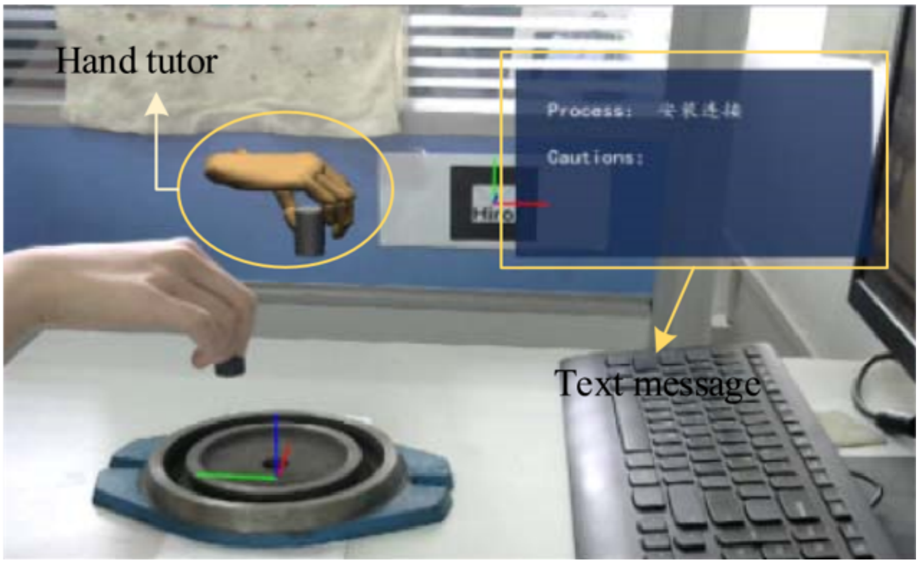

Figure 8. SAR Instructions with Hand Tutor. Adapted from “VR&AR Combined Manual Operation Instruction System on Industry Products: A Case Study.” By X. Yin, Y. Gu, S. Qui, and X. Fan, 2014, International Conference on Virtual Reality and Visualization.

They tested this system using a step by step assembly guide of a machine part using flat tongs. They found that the users received the instructions more naturally and instinctually using the gestures and animation, which they claim improved the users learning. They add that this system is still newly developed and that more complex products and manufacturing operations need to be tested, and that they will add more human-computer interaction methods to find further results.

3 Aim of this Thesis

The literature review offers many different examples of how AR is used in the maintenance industry. It debates many advantages and disadvantages of the technological state of the displays used in AR, comparisons between AR and more traditional mediums, user feedback, authoring solutions, and examples of how it can be used in training.

With this background information, the aim of this thesis is to first explore the current training and service setting of maintenance and repair technicians at a medtech company, and then discuss the possible employment of augmented reality in training and service. It will serve as the beginning phase of design-based research. In order to offer an effective solution to an instructional problem there must be an accurate analysis of the learning situation and participants, and without this analysis a proper solution cannot be recommended (Ertmer & Newby, 2013).

In order to properly analyze the current learning and working situation of the technicians the first objective of this thesis, is to gain an understanding of the types of issues and goals trainers have in the training and service of technicians in maintenance and repair. The second objective is to consider their opinions towards implementing AR as a way to help, enhance, or improve training and service. The position this research takes is not driven by seeking applications for the technology of AR, but rather it is concerned with the issues and goals conveyed by the trainers and subsequently how and which specific AR solutions could be employed to address such needs.

The following research questions have guided this thesis:

3.1 Research Questions

- What are some of the main issues and goals in training and service according to the trainers of maintenance and repair technicians at an international medtech company?
- What opinions and thoughts of the opportunities and challenges of using Augmented Reality in training and service are expressed by the trainers?

These objectives will provide the base analysis needed for future design work at this international medtech company, and potentially offer insight that is beneficial beyond this specific setting as well.

4 Theoretical Framework

The ideas and approaches of design-based research served as the framework for this study. Design-based research can be considered a series of approaches that have the intent of producing new theories, artifacts, and practices that can potentially impact learning and teaching in naturalistic settings (Barab & Squire, 2004). It focuses on understanding the messiness of real-world practice using context as a core part of the story, allowing for flexible design revision, multiple dependent variables, and capturing social interactions (Barab & Squire, 2004). As stated this thesis is the beginning analysis phase of design based research, and therefore does not offer a full understanding of this medtech company's practice. This analysis phase, however, aims to be a first step towards exploring a proper solution that can impact learning and teaching in a naturalistic setting, as described by the co-participants, which is why design-based research has been chosen to structure this study.

4.1 Historical Background

The term design experiment has informed the development of theories of instruction for over a century, but it is usually attributed to the work of Brown (1992) and Collins (1992) (Cobb et al., 2003)

Brown (1992) described her attempts to engage in design experiments intended to transform classrooms into learning environments that encourage reflective practice. She discussed her progression from the study of laboratory learning to classroom observations and experimentation. She said the evolution of her work moved towards a theoretical model of learning and instruction grounded in a firm empirical base. The situated nature of her research lent itself to practical application, and she attempted to engineer inventions that have recognizable standards based on theoretical descriptions rendering them reliable and repeatable.

Collins (1992) sought to construct a systematic methodology for conducting design experiments, and guide the implementation of future innovations by developing a design theory. He said, "Technology provides us with powerful tools to try out different designs so that, instead of theories of education, we can begin to develop a science of education" (Collins, 1992, p. 4). He goes on to explain that it cannot be an analytical science that determines how different designs of learning environments contribute to learning, motivation, and cooperation but rather it must be a design science.

4.2 Application in Design-based Research

When examining potential learning theories to apply to design-based research it is critical to select a theory whose instructional strategies offer the optimal means for achieving desired outcomes, and the degree of cognitive processing required of the learner by the specific task (Ertmer & Newby, 2013). According to Ertmer & Newby (2013) the designer needs to think about what level of professional knowledge the learner has, and the requirements of the task to be learned. They state that the critical question instructional designers must ask is not which theory is best, but which theory is the most effective in developing mastery of specific tasks by specific learners.

When considering the use of AR, and the comments from the trainers, which will be discussed later in this thesis, it seemed pertinent to discuss constructivism in more detail, and how it can be applied to design-based research.

4.2.1 Constructivism

There are two main approaches to constructivism both of which have the foundational belief that students learn by constructing their own knowledge (Schcolnik, Kol, & Abarbanel, 2016). Cognitive constructivism is associated with the work of Piaget which concentrates on the importance of the mind in learning, and social constructivism, associated with Vygotsky, which focuses on the role the environment and the interactions between learners (Schcolnik et al., 2016)

The important epistemological assumption of constructivism is that individuals create meaning from their own experiences, and that reality is constructed through interpreting perceptual experiences of the external world which is unique to each individual's beliefs (Jonassen, 1991).

Rather than attempting to map a particular reality onto learners, constructivists recommend that designers help them construct their own meaningful and conceptually functional representations of the external world by creating real-world environments that utilize the context in which the learning is relevant (Jonassen, 1991). Furthermore instruction should focus on providing tools and environments for helping learners interpret the many perspectives of the world in creating their own world view (Jonassen, 1991). The task of the designer, therefore, is to instruct the learner on how to construct meaning, and how to effectively evaluate, monitor and update those constructions (Ertmer & Newby, 2013). This can be done aligning and designing experiences for the learner so that authentic and relevant contexts can be experienced (Ertmer & Newby, 2013).

5 Research Approach

This section will describe the research approach used for this thesis. It will include information about the setting of the study, the co-participants, the data collection, research and analysis, methodological and ethical considerations. The basic structure of the research is an initial interview, followed by weeks of research that was collected based on the findings of the first interview which was then summarized and used as stimulus material for the second interview, and finally a discussion and conclusions based on all of the findings from the two interviews.

5.1 Setting

This thesis was conducted at an international medtech company. This company provides products and solutions to healthcare and life sciences all over the world.

The section of the company called Academy, deals with a variety of training and certifications for employees. Considering the aim for this thesis is the training and service of maintenance and repair procedures the focus is the training the Academy organizes for the company's technicians. These technicians go out to hospitals or other facilities to do repairs or maintenance work on machines sold by this medtech company. For this project, two trainers of these technicians volunteered to participate.

5.2 Co-Participants

In design-based research participants are not regarded as subjects that are assigned to experimental treatments, but they are seen as co-participants in both the design and analysis (Barab & Squire, 2004). Both co-participants were male, and have worked in many different positions within the company. They were labeled G001 and G002 in the transcripts to provide anonymity, and will be labeled as such from now on as well. G001 is currently a lead technical trainer, and it is the lead trainer's job to teach the technicians the purpose of the products, the process of the machines, and troubleshooting. Troubleshooting, in this case, means when a machine has an error and a technician is called to fix the problem on-site. Previously, G001 worked as a technician for four years, and before that in one of the company's factories. G001 was a local trainer before requesting and receiving his current position with the Academy.

G002 develops assessments for classrooms and recertification, and overall content for the lead trainers. Previously he worked as a technical lead trainer, in technical support, a technician for five years, and in one of the company's factories. G002 was recruited by the Academy to have the role in which he is currently employed.

5.3 Data Collection and Research Process

Two rounds of interviews were conducted. These were separated in time by a phase of research and testing of different AR solutions reflecting the needs expressed in the initial interview and used as stimulus material for the second interview. The topic of the first interview, was directed toward the first research question:

- What are some of the main issues and goals in training and service according to the trainers of maintenance and repair technicians at an international medtech company?

After this interview the author spent several weeks researching AR and presented a summary of articles, videos, examples and information about AR and its current uses, and also attempted to create an AR demonstration to present to the trainers. This work was used as stimulus material to provoke and sustain discussion for the second interview, and to help them understand and imagine implementing the technology in their own training and work.

The trainers having this new knowledge the second interview was conducted and offers insight into the second research question:

- What opinions and thoughts of the opportunities and challenges of using Augmented Reality in training and service are expressed by the trainers?

For both interviews the data were collected using unstructured interviews with technician trainers in a group setting. Conducting the interviews in a group setting allows the participants to interact and build off of each other's answers which can generate data and ideas that may not have been uncovered using one to one interviews (Plummer-D'Amato, 2008). Unstructured interviews allow flexibility because it is comprised more of themes rather than specific questions which can enable the participants thoughts to be explored in depth which generates rich data (Doody & Noonan, 2013).

The general themes for the interviews included questions from Ertmer & Newby (2013). These questions were not asked out right to the co-participants, but were used as a guide to ensure the necessary information was obtained from the discussions.

- What are the situational and contextual constraints of the application?
- What is the degree of individual differences among the learners?
- What form of solutions will or will not be accepted by the learners as well as by those actually teaching the materials?

Finally, as was stated in design-based research participants are treated as co-participants in both the design and analysis, because for the design experiment to be successful, it must work within the constraints defined by the teachers, or in this case the trainers, and answer their questions (Collins, 1992). That is why for this pre-design phase interviews were used with the trainers so they could act as co-participants in this beginning phase of design research.

5.4 Data Analysis

A thematic analysis was used based on six guiding steps outlined by Braun & Clarke (2006).

- Transcribe the data, in order to become familiar with the data and generate initial ideas.
- Code interesting features in the data in a systematic fashion.
- Collate those codes into potential themes.
- Review the themes to create a thematic map based on the analysis.
- Generate clear definitions and names for each theme.
- Report the final analysis by selecting vivid compelling extracts relating back of the analysis to the research questions and literature.

Thematic analysis is a useful method for identifying, analyzing and reporting patterns within data, and organizes the data set in rich detail (Braun & Clarke, 2006). The initial codes aim to produce a systematic recording of the themes and issues addressed in the interviews and to link them together under a reasonable system (McLellan, MacQueen, & Neidig, 2003). Furthermore, using sensitized concepts as a starting point to develop thematic categories from the data can give a sense of how observed instances of a phenomenon might fit within conceptual categories (Bowen, 2006). The themes generated, and how they relate back to the research questions for this thesis are described in the interview findings sections of this thesis.

5.5 Methodological Considerations

To help ensure the credibility of the results, the following concerns of data collection and analysis have been addressed and considered.

First, unstructured interviews tend to be more beneficial when the interviewer is more experienced (Doody & Noonan, 2013), but as they are based on the idea that little knowledge is known it can be beneficial to use themes rather than specific questions (Ryan, Coughlan, & Cronin, 2009) which seemed appropriate for this project, and, as previously stated, will still generate rich data.

Second, using thematic analysis does not require as much technical knowledge as other approaches, and can be used effectively by those who are still learning qualitative techniques (Braun & Clarke, 2006). Nevertheless, there are a few difficulties. There is a risk that no analysis occurs at all because the research mistakenly strings together extracts with little or no analytical narrative, or simply uses the research questions as the reported themes. That the themes are too similar and overlap, cannot be supported, or that the interpretations of the data do not match the theoretical framework underpinning the research (Braun & Clarke, 2006). The hope is that these difficulties have been avoided as much as possible by applying the six steps from Braun & Clarke (2006), and using the guiding questions from Ertmer & Newby (2013) as outlined in the data analysis section of this thesis. Furthermore, the trainers were shown the interview findings and direct quotes that were included in this thesis. They both agreed that the analysis accurately represents the conversations from the two interviews.

5.6 Ethical considerations

Using some standards from Doody & Noonan (2013), the co-participants were told briefly about the project, how their answers would be used, that everything would be kept anonymous, and that they were free to leave the project at any time before beginning the interview. They were also informed they would be given the final copy of their quotes or comments before the project was completed. They both agreed and signed a consent form willingly, and said they understood the project and felt comfortable continuing.

To guarantee the anonymity of the co-participants their names and the name of the company are not mentioned in this thesis. The description of their jobs and experience within the company are necessary to establish their knowledge and give credit to their insights, but were kept as general as possible to further protect their identity.

6 First Interview

The first interview was about 30 minutes, had no predetermined questions but rather consisted of themes, and was transcribed and analyzed as described previously in the data collection and analysis section of this thesis. Again the objective of this first interview was to explore the current learning and working situation of the technicians and to gain an understanding of the types of issues and goals trainers have in the training and service.

Three main themes were generated after the analysis: Spread Knowledge, Build Confidence, and Standardized Service.

6.1 Training and Working

Before delving into the first interview and the categories generated from the thematic analysis it is perhaps beneficial to first explain how the trainers described their current training methods and the technicians' work.

Beginning with training, the trainers said they have recently implemented e-learning courses that the technicians have to complete before they can attend classroom training. After completing these e-learning courses, the technicians begin with fundamental classes that can last anywhere from four days to one week. The experience level between the technicians in the fundamental classes can vary between some being brand new employees and some with up to five years of experience in the company.

In these classroom trainings, the trainers teach the technicians how to read the piping and instrumentation (P&I) and electrical diagrams, where to find information in the service manual, how to read the panels and signals on the machines, and how to physically remove and replace spare parts. These classroom trainings are not always the same. The trainers try and determine what level of training is needed and possible with the group of technicians that are in each training. Sometimes they spend more time on reading the diagrams than working on the machines or vice versa.

After the technicians have completed their training they begin working on-site with customers. They usually perform preventative maintenance or repairs on the machines by themselves. The trainers said the technicians do not take the service manual with them on location, but that they do have a document which states what should be checked, replaced, or serviced. The trainers said this is only a checklist that the technicians hand over to the customer when they are done working on the machine, and that it is created by a whole different branch of the company. It is not used as information or as a guide for the technicians while they are on-site. In general, they said the technicians rely on their own knowledge and experience.

6.2 First Interview Findings

6.2.1 Spread Knowledge

Both trainers said their main goal is to spread the knowledge. One reason is because the knowledge between the technicians is very diverse. The technicians have varying past work experience and education. The trainers said some could be fully certified electrical engineers while some could be truck drivers, and that they, the trainers, are not a part of the recruiting process. This diverse range of knowledge makes it difficult to organize classroom trainings, because they do not want to overwhelm the newer technicians, but they also do not want the experienced technicians to become bored.

Another reason this is their main goal, is that sometimes incorrect knowledge is being shared between the different sales and service units throughout the company. G001 described a conversation he had with a technician, where the technician had invented his own procedure of switching valves on a machine every year. This procedure, G001 said, is not what is best for the machine, and it is actually more expensive for the customer. It is procedures like this that are unfortunately shared with other technicians.

Excerpt 1:

G001: Ha and what will happen is when they have a new guy they will teach him that way

G002. Yup

G001: And

I: It just keeps going and going

G001: Yeah

I: In the wrong direction

G002: And the next thing he's a technical trainer also

G001: Yeah (laugher)

As mentioned, in order to level the range of knowledge between the technicians, the trainers have recently implemented e-learning courses that the technicians are to complete before entering the classroom trainings.

6.2.2 Build Confidence

Another reason the trainers say they have developed the pre e-learning courses is so that technicians can walk into classroom trainings, and have confidence. Build Confidence, is the second theme generated from the data analysis.

In the classroom training, they say that with more confidence the technicians will be able to work more hands-on. It can be a safe environment for them to try things, and make mistakes. The trainers believe the technicians can learn through their mistakes, and that is why they want to give them the opportunity to have more practical training before going on-site with the customers.

Excerpt 2:

G001: We want a place where they can try and

G002: Oh I don't know yeah

G001: Fail and fail and in the end like ok we got it

I: Yeah

G002: Cuz here we have the safe environment

G001: Yeah

G002: Here they can…they can do the mistakes here

6.2.3 Standardized Service

The final theme, Standardized Service, is what the trainers would like to establish throughout the company. G002 describes this goal by describing his opinion of how the car industry functions as an example.

Excerpt 3:

G002: Yeah yeah yeah exactly the same as in the car industry

I: Yeah

G002: If you have a Volvo and you leave it in Halmstad or in France

I: Mmhmm

G002: Or in Spain

G001: Yeah

G002: The service the maintenance is the same

I: Mmhmm

G002: That is what we want too…we want to try to achieve that on our products also

Currently this is a difficult goal for them to achieve, because there is no set procedure for how a technician should approach preventative maintenance or repair. The process relies on the technician’s expertise, and the trainers say this has not led to good results. They said this is because the technician's just replace parts instead of really understanding the problem. The trainers go on to explain that the customer expects the machine to be fixed on the first visit by the technician, and that is why training is so important. They want the technicians to know how to fix the problem, and not just replace parts as they do today. Both G001 and G002, being technicians previously, said they too used to operate in the same manner and that they understand that it is much easier to replace parts rather than to diagnose the problem.

They, therefore, try to give the technicians some guides for how they can approach preventative maintenance and repair by encouraging the technicians to use the P&I diagrams and paper documentation. However, they said the technicians tend to resist using paper documentation in general. G002 describes a classroom scenario where they instruct the technicians to use the diagrams and documentation they have provided to solve a problem they created on the machine, but when the technicians begin the procedure they always begin by looking at the machine instead of consulting the paper documentation or P&I diagrams. They believe this is because the technician's feel they will solve the problem faster without consulting the documentation, and because they do not actually know how to read it.

To conclude, the trainers explain how this inconsistent service has created dissatisfaction with the Academy branch within the company, and even the company as a whole to customers. They said the quality of customer service and quality of work has gone down the last few years, and they need to build up their reputation again.

6.3 Summary

To point back to the first research question for this research, another way to frame the information generated from the first interview is to discern the trainer's main issues and goals.

Their main issues are the diverse range of knowledge between the technicians. Which makes it difficult to organize classroom training and causes the more experienced technicians to develop and share their own sometimes incorrect procedures. In general, the technicians resist using paper documentation, because they cannot properly read the diagrams and believe they will solve problems faster by looking to the machine. Finally, there is no on-site support or standard procedure for the technicians.

Their main goals are to create classroom trainings that allows for more hands-on practice with the machines. They want to create a safe environment where the technicians can learn from their mistakes. Ultimately, the trainers want to create a more standardized service to improve the quality of work and their reputation.

7 Stimulus Material

After the first interview the author spent several weeks reviewing articles situated in maintenance and repair settings, which have been mentioned in the literature review of this thesis, as well as articles that explained and examined AR more generally. This information was summarized and presented to the trainers as stimulus material. Stimulus material can be anything (cartoons, pictures, newspaper articles etc.) that is relevant to the research agenda, and will provoke and sustain discussion (Barbour, 2008). When planning the stimulus material and consequential discussion it is key to anticipate the possible responses and be certain the discussion will be related to the research questions (Barbour, 2008).

The stimulus material that was presented intended to give the trainers a clear definition of AR, descriptions of how the different displays work, their advantages and disadvantages, and some examples from the literature how AR has been used in maintenance and repair.

To further inform the trainers some videos were presented to show what the different AR displays look like, their display capabilities and different interfaces. The videos showed how AR is currently being used in maintenance and repair, and also surgeries, navigation, and interactive gaming. Additionally, the trainers downloaded and tried an app entitled "augmented repair" during the interview. It is a free app developed by Re'Flekt, a technology that enables businesses to create their own Augmented and mixed reality applications ("Re'Flekt", 2016). This app demonstrates a step by step repair procedure on a digital coffee machine.

Finally, the author also attempted to create a small AR demonstration using a HHD on one of the medtech company's machines. One attempt was made on HP Reveal, and another attempt was made in Unity with Vuforia.

The following section will describe in more detail the stimulus material that was chosen to help the trainers understand the technology and its current capabilities, and to ensure the discussion would be relevant to the second research question.

7.1 Stimulus Material about Different Displays

First, after a thorough review of the literature it seemed valuable to talk about each of the AR displays in detail: HMD, HHD, and SAR. According to the literature it stands to follow that HMDs will be highly useful in the field, and they are an obvious choice for work in the industry, given its ability to be used hands-free by the user, but there are some technological difficulties that have yet to be improved before they are wholly suitable. Naturally discussing how HMDs could be employed in learning and service with the trainers is insightful, but currently HMDs could in actuality only be used in a limited function. HHDs, such as tablets or Smartphones, could be more useful right now, because of their affordability and power.

For that reason, showing the technicians the "augmented repair" app was highly informative, and a great example of how accurate and clear instruction and training could be with HHDs. The trainers were very impressed with the app. They needed no instruction how to use it, and the digital coffee machine was so realistic that while G001 moved through the steps on the app there were several occasions where he reached out to interact with the buttons on the virtual coffee machine instead of interacting with the display on his Smartphone. They both thought it would work "perfectly" for some of their trainings. More of their thoughts on this are elaborated in the second interview findings.

It was not possible to show an example of SAR, besides some videos, but the projectors are powerful and can be accurate and in the right setting can be a viable option for training and support.

Considering the variety of options between the different devices it was important to make certain all of the displays were considered during the interview with the trainers.

7.2 Stimulus Material from the Literature

Next, some examples from the literature were shown to the trainers in order to give them a brief overview of the types of studies and findings currently being done within the same field.

To begin with, some of the user feedback was discussed from current studies. This information is useful for the trainers to know so they can anticipate how their own technicians might feel towards actually using the technology. Much has already been mentioned in detail in the literature review of this thesis, but to summarize again, for the trainers the feedback was organized into positive and negative comments found in the studies. Some positive comments were that the systems were easy to use and understand, users thought AR applications would be easier to update than paper, they liked that it used less text and was more image based, they did not mind using HHDs, and they thought that AR applications would help them complete tasks. Some negative comments were that users thought colleagues would be resistant to using AR devices, the technology was not robust enough, that it would get dirty, has poor lighting, does not have enough battery life, they had issues with HMDs or wearables falling off or moving, and that users would not want to use it every day.

Following this Fiorentino, Radkowski, Boccaccio, & Uva's (2016) study, described previously in this thesis, was discussed. This study showed the trainers how AR could be used on-site and how users could trigger step by step instructions while they worked.

Also, Engelke et al.'s (2015) study was discussed, specifically to show the 3 different interfaces they developed that users could choose between: AR mode, VR, mode, and 2D mode. The different modes gave the trainers an idea of the options in how the material could be displayed to the technicians.

7.3 Stimulus Material on AR Creation

In another effort to show the trainers how AR could be employed specifically on one of their own machines using a HHD the author attempted to create a small AR application. These attempts did not result in a functioning AR demonstration, but the experience was still shared with the trainers to inform them of the time and skills required to create AR applications themselves.

From the outset it was difficult to gain access to the machine in the Academy's training room. In order to create a simple step by step demonstration it was necessary to acquire an image of the machine and work next to it. The machine, unfortunately, was usually unavailable during working hours and was being actively used in training, which meant it was often left in disarray with spare parts removed. The trainers had a few images saved, however, and they were enough, although not ideal, to use for the following attempts.

7.3.1 HP Reveal

Initially, HP reveal was used to try and create this simple demonstration. HP reveal's website offers a web studio that enables anyone to easily create, manage, and track augmented reality applications ("HP Reveal", 2018). First the user downloads the free HP reveal app and creates an account. Then, through the app, pictures can be taken of objects that will be used as targets or fiduciary markers. Once the target image is added to the user's account database, which can be kept private or shared, digital objects can be overlaid on to the target image. The app has a few available objects that can be overlaid on the target, or the user can use the HP reveal studio to upload or create their own digital objects. Digital objects can be videos, text boxes, or animated figures such as plants, arrows, or animals.

Unfortunately, the HP reveal studio cannot be managed on Smartphones yet, so the user needs to create their own objects on a computer. Once the target and digital overlay is chosen and saved the user can return to the app's home screen and push the app's bottom icon to have the app search for target objects in the real environment. Once the app identifies a target it will display the digital object.

Figure 9. HP Reveal App Interface. Adapted from "HP Reveal". 2018, Retrieved from https://studio.hpreveal.com/landing.

The app and studio was relatively easy to manage, but the quality did not seem to be sufficient enough for this project. The target objects were difficult for the app to recognize, due again to the technological difficulties with lighting conditions mentioned already, and it was difficult to place the digital objects in a precise location on the target image. Which again, as mentioned in the introduction of this thesis, is something that is needed for maintenance and repair work.

7.3.2 Vuforia and Unity

Since the AR applications created in HP reveal did not seem accurate enough the next attempt used Unity with Vuforia. Unity is a development platform for creating 2D and 3D multiplatform games and interactive experiences ("Unity", 2018). Unity integrates the Vuforia engine, which is a software development kit that supports the creation of augmented reality applications by implementing vision technology to recognize and track image targets and simple 3D objects in real time (Chen, Lee, & Linn, 2016).

To begin the user creates an account on Vuforia's website where they can create databases of uploaded target images. The website will generate a license key for each database that can be used in Unity. The user then installs and creates a new project in Unity, and activates the Vuforia engine thereby connecting their Vuforia account in Unity. Now the user is able to overlay objects on target images and create AR experiences.

There were a few issues when trying to create an AR demonstration using Vuforia and Unity. The first issue for the author was that some coding knowledge is required. Unity supports C#, Boo, or a dialect of JavaScript (“Unity”, 2018). The website does offer some tutorials and guides for beginners.

Vuforia supports development for Android and iOS in Unity that can be transferred to both platforms, Windows 7 and OS x 10.11 and above, and, therefore, making AR applications created in Vuforia compatible with a broad range of mobile devices (“Vuforia”, 2018). However, the type of devices needed are a bit more limited when using Vuforia’s object recognition scanner.

A feature that Vuforia offers is object recognition which supports the scanning and recognition of 3D objects (“Vuforia”, 2018). This feature is especially significant for this medtech company considering the technicians work on machines all over the world. If the devices could recognize spare parts it would not matter where in the world the machines are located, they would still be recognized. All that would be needed was a database of scanned parts. Right now, the Vuforia Object Scanner is supported only on the Samsung Galaxy S5 and Google Nexus 5 running Android version 4.2 and above devices (“Vuforia”, 2018). The user needs one of the aforementioned devices and to print the object scanning target. The object is placed on the scanning target, scanned using the Vuforia object scanner app, and saved in the user’s database. The scanned object will then be recognized in the completed app on the user’s device.

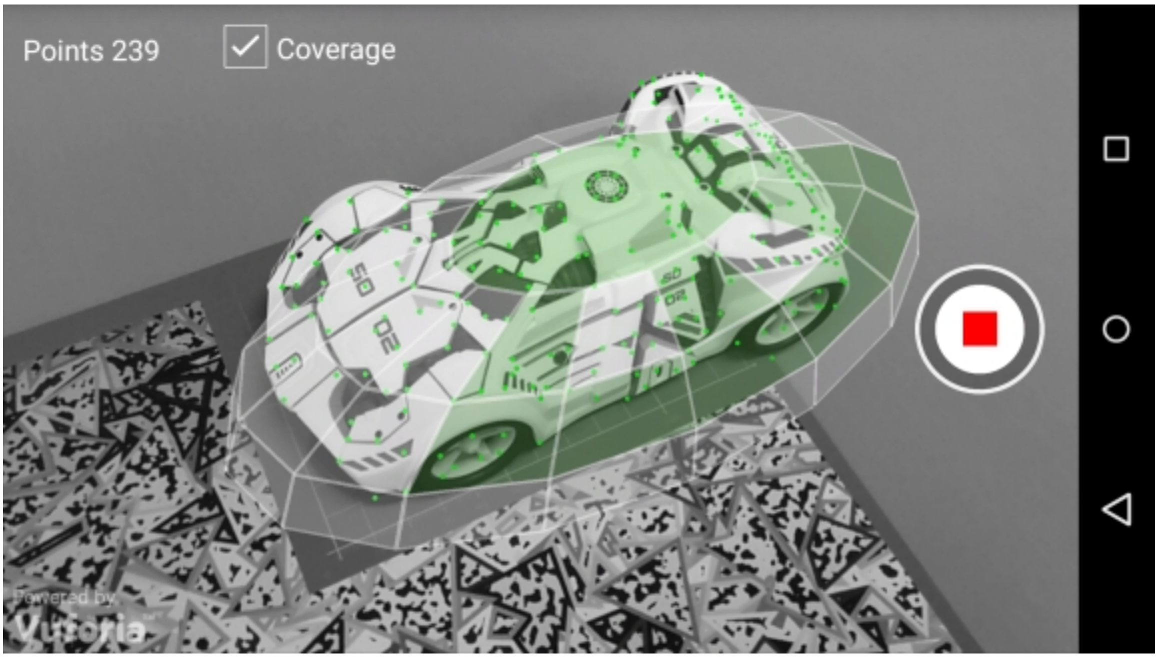

Figure 10. Vuforia 3D Scanning App. Adapted from “Vuforia”. 2018, Retrieved from https://developer.vuforia.com.

In order to try this feature the author was able to borrow some pipes from the machine, and a Galaxy S5. The scanning was intuitive, but the digital objects overlaid on the target were jittery and unstable. It also look a great deal of light for the app to be able to register the object properly.

The final issue was the time limitation of this project. Unity offers a whole range of possibilities and options that can be used by beginning or professional designers, but it is a large program that does take some time to learn. In the end, it was not possible for the author to create a useful AR demonstration for this project due to the time limitation, lack of sufficient coding knowledge, and the limited access to the machine, the borrowed pipes and the Galaxy S5.

Although these attempts did not end as intended, this experience did inform the trainers about HP Reveal and Vuforia and Unity. Again, by discussing these programs' strengths and weaknesses the trainers were informed of the knowledge necessary to use these programs, and the time it would take to create AR-based training or guidance applications if they wanted to develop these AR applications themselves. Moreover, the author, in attempting to create an AR application experienced first-hand the strengths and weaknesses of the technology which allowed for a more accurate representation of what the trainers could expect by implementing this technology in their training and work.

8 Second Interview

After the stimulus material was presented the second interview began. Again the objective of the second interview was to consider the trainers' opinions of the opportunities and challenges of using AR in training and service. The following section is organized using the three categories generated from the first interview: Spread Knowledge, Build Confidence, and Standardized Service. This interview was about 44 minutes and was conducted the same as the first; an unstructured interview with both trainers in a group setting.

8.1 Second Interview Findings

8.1.1 Spread Knowledge

To begin, the trainers thought that AR could be used along with the e-learning courses prior to classroom trainings. They felt an application similar to the coffee machine procedure in the "augmented repair" app would be a good way for the technician's to train and learn a step by step procedure. The trainers said something similar would work "perfectly", and immediately thought of an example of a small table top machine on which the technicians could practice dismantling the machine's parts.

Excerpt 4:

G002: yeah yeah it would be interesting to use on a case here as just a small table top sterilizer

G001: yeah

G002: to just dismantle the plates

I: mmhmm

G002: just for an example to show….that would be quite

G001: work perfectly I think

When asked if they thought the expert technicians could benefit from the technology as well, the trainers mentioned they thought there could be some resistance especially from those who were a little older. The trainers felt it could be difficult for them to take in a new technology, but if it were presented in a good way they thought they could also learn and benefit from it. Especially, they said when using Smartphones, since almost everyone has their own and knows how to operate them. They continued by saying experts are not experts on all things, and that expert technicians need to have access to this type of information and practice training whether they think so or not.

8.1.2 Build Confidence

The trainers believe the more hands-on practice the technicians perform, the more confident they will feel during classroom trainings and on-site. They referred again to the "augmented repair" app where the technicians can have this type of practice at home. They felt this extra practice would put the technicians more on the same knowledge level when beginning classroom trainings.

They mentioned again the current e-learning courses which are comprised of text PDFs that the technicians simply read through, and at the end there is a small assessment to determine how much they understood. The trainers said they do not feel this is the best way to present the material. G002 explained how he personally searches for YouTube instructional videos if he needs new information rather than reading instructions. He said that the technicians, also, prefer the practical training over the lectures during classroom training, and that they would like to add more than just text to the e-learnings.

Excerpt 5:

G002: we stand and explain and explain and explain and then the last two and half days is just practical exercises

G001: yeah

G002: we create errors (in the machine)

I: mmhmm

G002: and then come into the room and say the machine is broken and we don't know what to do please fix it

G001: yeah (laughter)

G002: which parts do you think they are...is the best for them the most fun for them

I: right

G002: the practical

When asked if the trainers thought SAR could be used, they came up with the idea of re-creating some custom made machines from a branch in the company referred to as life science, which they rarely have access to. In order to see and train with these machines, technicians and trainers from around the world are currently required to travel to the factories where they are built. The trainers thought that by using SAR they could recreate these big machines during classroom trainings that would allow the trainers to teach the technicians how to perform maintenance and repair without travel or concern of availability.

8.1.3 Standardized Service

Finally, to support the technicians more while working on-site and towards creating a more standardized service, the trainers thought using an AR application that tagged, highlighted, or identified the different parts on the machines could be helpful. Instead of relying on the service manual or paper documents, which as was mentioned the trainers say the technicians do not use, the technicians could just pull out a Smartphone or mobile device, and have the AR application identify and label the different parts or areas on the machine.

The trainers also had the idea to display the P&I and electrical diagrams directly on the machine instead of the technicians needing to use the paper documents. G002 said it would make it much easier if the technicians wore AR glasses and had the information displayed directly on the machine allowing them to work more efficiently and hands-free.

The trainers also mentioned they have no feedback about the technician's work on-site besides from the customers or the technicians themselves. They would like to be able to receive other forms of feedback on how the technicians work, and if there were any areas of service in which they struggle.

Overall, the trainers thought that developing these AR applications would create a sort of toolbox for the technicians to refer to, and that it would be easier for them to use in comparison to the service manuals or paper documents. The trainers also said they think the technicians feel abandoned, and that this toolbox or guiding resource would give them more support.

In conclusion, the trainers mentioned a continuing problem for the entire academy branch of the company. The trainers explained they often have lots of ideas and discuss different and better ways of training, but that after these discussions no action or follow up is taken. Mostly they said because no one has the time or energy to develop them.

Excerpt 6:

G002:…we have been discussing this a lot with all this idea

G001: yeah

G002: how we could

I: mmhmm

G002: be better in training how we can use it in training... to increase the knowledge spread the knowledge and everything but then we come to a certain point

I: mmhm

G002: and then it stops

G001: yeah

G002: it gets too complicated it gets too big so no one actually...has the energy to take on the project and carry on

8.2 Summary

To summarize the discussion in the second interview there were several opportunities the trainers identified in using AR in training and service.

The opportunities discussed were how AR applications could be used along with the current e-learning courses where the technicians could practice the step by step procedures rather than only reading information in the form of PDFs. They thought even the more expert technicians would benefit from having this practice and resources if the technology was presented to them in an encouraging way.

They envisioned some ideas of how they could use smartphones or tablets to train how to dismantle a small table top machine, how SAR could be used to create custom made machines which are currently difficult to access, and how the technicians could work hands-free using HMDs while having the electrical diagram displayed directly on the machine.

Finally, they liked the idea of having feedback for how the technicians work on-site, and overall they felt that these AR applications would create a helpful toolbox of guides and information for the technicians to access when needed

While there were many opportunities identified some challenges were discussed as well. One disadvantage the trainers discussed was the resistance to technology particularly from older technicians. The biggest challenge they felt was the time and energy it would take to develop and create these AR applications, because this is something they know the entire academy has already been struggling with in the past.

9 Discussion

The following section will discuss the results of the two interviews with the trainers. After looking at the comments and categories generated from the analysis the outcomes point to three main areas in which developing AR applications could be applied for the training and service of the technicians at this medtech company: pre-learning, classroom training, and on-site service.

9.1 Pre-learning

The type of learning environment the trainers have mentioned corresponds to some principles from constructivism, and are directly relevant for the instructional designer: to anchor learning in meaningful contexts, actively use what is learned, having information displayed in a variety of ways, supporting the use of problem solving skills allowing learners to go beyond the given information, and having assessment focused on the transfer of knowledge and skills (Ertmer & Newby, 2013). Creating AR-based training sessions that facilitate hands-on practice in a relevant context would help build the learning environment the trainers wish to create.

Additionally, the trainers feel AR-based training sessions would benefit both the new and experienced technicians. The issue of diverse knowledge among service technicians is a known issue within companies and is discussed in the literature. Experienced technicians have accumulated invaluable knowledge over their years of experience and know how to precisely maintain and repair complex machinery (Webel et al., 2012).This knowledge, however, is rarely documented and is often restricted to only a few people, but is crucial for companies as these skills contribute to savings in time and cost (Webel et al., 2012). AR applications could help bridge the knowledge gap between experienced and new technicians by allowing more hands-on practice and the digitization of technical documentation and procedures which are easier to update, store, transport, use, and translate into all languages (Gattullo et al., 2017).

Creating AR-based training sessions would allow the technicians more hands-on practice and knowledge prior to classroom trainings. Which would help level the range of knowledge between the new and experienced technicians, and likewise, as the trainers believe, will give them more confidence.

For future work something similar to the “augmented repair” app discussed in the second interview or like the work of Yin, Gu, Qui, & Fan (2014) discussed in the literature review, could be created that would train the technicians in step by step procedures, or as the trainers suggested the dismantling of a small table top sterilizer, and allow them to mimic and practice those procedures physically. These types of training sessions would give the technicians the opportunity to perform the actual task while also accessing additional training material, such as the current text PDFs, which would facilitate additional learning (Webel et al., 2012).

Something to keep in mind as well when developing AR-based training is that users can become dependent on the visual features, and not be able to perform the task when the training ends or the technology fails (Webel et al., 2012). The level of guidance in the AR training system should reflect the current training phase and differ from AR guiding applications (Webel et al., 2012).

9.2 Classroom training

The trainers would also like the classroom trainings to consist of hands-on work and to be a safe environment where the technicians can ask questions and make mistakes. In constructivism learners are encouraged to construct their own understandings and then to validate them through social negotiation (Ertmer & Newby, 2013). As the learner gains more confidence and experience they move into a collaborative phase of learning where discussion becomes crucial, and by articulating their own understandings they become more aware and better at communicating their own knowledge (Ertmer & Newby, 2013). SAR being integrated into the environment without requiring the user to operate an individual display, allows collaboration between users (Carmigniani et al., 2011). By developing interactive SAR for classroom trainings the technicians would be able to collaborate and share their knowledge with others.

Additionally, the trainers observed during classroom trainings that the technicians are resistant to paper documents, because they think they will solve the problem faster by looking to the machine and they lack the experience to properly read the documents.

Garfinkel (2002) writes about the challenges of understanding instructions and says that the act of following and reading them in the course of work is dependent on when, and what level of knowledge the reader has as to make the instructions relevant. He says it is one matter to read instructions and another to read them with the intent of acting on them. Often the perception of the reader is that the instructions do not have anything to do with the task at hand, or with their current situation and knowledge. It is only in hindsight that the person consulting the instructions gains understanding, but before that they are faced with problems of clarity, completeness, followability or factual adequacy while consulting the instructions during a task. This disconnect is probably what is happening between the trainers and the technicians. The trainers have the gift of hindsight, while the technicians are new to the instructions and are struggling to link the current stage of instructions with the task at hand.

AR-based training or guidance systems could help minimize the difficulty of following instructions or diagrams. AR having the ability to overlaying information directly on the real world changes how information is displayed and manipulated enabling the environment to be interpreted with more knowledge (Orlando & Markon, 2017). Much of the user feedback from the literature review also indicated that users prefer the visual nature of AR, and thought it was easy to understand and follow.

Finally, AR-based training would offer a needed solution in the case where it is not possible to access physical machines or parts. The resources and time currently expended to access the company's custom made machines would be minimized using SAR to re-create the machines, and again also create an interactive learning environment along with the trainers. AR cannot perhaps fully substitute the benefits of working on the physical machines or simulate the physical labor, but it could offer authentic experiences and relevant contexts for the technicians. In using AR, the learners could create a mapping between the training and the real task (Webel et al., 2012).

9.3 On-site Service

AR could also offer support, or as the trainers said a toolbox of information, that the technicians could access and use while working on-site.

Overlaying electrical diagrams, tagging or identifying different parts on the machine would be useful information for the technicians, and they would not have to turn and consult difficult paper instructions while they work. This would minimize issues of divided attention, the ability to respond simultaneously to multiple tasks, because they would only have to attend to the real world working space and not have to turn away to consult the information in the instructions (Uva et al., 2018). A well-designed visual workspace can also optimize the user’s chance of detecting critical information rapidly (Steelman, McCarley, & Wickens, 2017).

For future work something compared to the work of Engelke et al., 2015, which offered three different interfaces, could be developed for the technicians to use on a HMD or HHD. Each interface could offer different information that the technician could open and apply on-site based on their needs or task.

Finally, the use of an on-site AR platform would allow for the measurement and evaluation of the users' performance (Webel et al., 2012). The AR application could record data on time spent by the technician on each step of the procedure, making it possible to understand which step needs improvement in the procedure (Havard et al., 2016). If the technicians used AR devices while they worked, this information could be fed back to the larger organization where the trainers could use the data to identify problem areas and tailor improved instructions and training sessions based on this feedback.

10 Limitations

There are a few limitations that should be taken into consideration when reviewing the results of this thesis.

The first limitation, is the time constraints in which this research was conducted. The interviews were confined to the time in which the co-participants had to volunteer, and the whole project was executed in an eight month time frame.

A second limitation could be said that there were a lack of co-participants for the interviews. With more time and access it would have perhaps been valuable and interesting to add more co-participants from other companies as well to add more representation to the data. However, it was still deemed beneficial to have too few co-participants who were actively engaged and available, rather than too many who were potentially less interested in contributing to the research.

Finally, after reviewing the interview transcripts there was much more discussion in the second interview than compared to the first. Having themes rather than specific questions in the interviews did allow for freedom and flexibility of discussion for the co-participants, but it is was difficult to sustain discussion at times in the first interview. This is a common problem when conducting unstructured interviews, and can make the data difficult to properly analyse and code (Doody & Noonan, 2013). The second interview appeared to be more successful in sustaining discussion mostly it seemed because it was combined with the stimulus material, which motivated the discussion more naturally for the co-participants.

11 Conclusion

The aim of this thesis was to explore the current training and service setting of maintenance and repair technicians at a medtech company, and discuss the opportunities and challenges of using AR in training and service. This analysis phase of design-based research has resulted in the identification of the trainer's issues and goals in training and service by analyzing them in three categories: Spread Knowledge, Build Confidence, and Standardized Service.

Also, after the use of stimulus material the opportunities and challenges that AR could offer to help or enhance training and service were discussed with the trainers, and the final discussion of this thesis considered how AR could create the learning environment and offer on-site support that the trainers would like to establish.

11.1 Implications and Future Work

This study shows that AR applications can have implications for settings other than maintenance and repair. Some issues mentioned in the interviews and discussion are not constrained to this medtech company, and in which the application of AR training or AR guidance could be beneficial:

- Diverse range of knowledge
- Resistance to consulting technical documentation
- Difficulties in following written step by step procedures
- Creating learning environments that offer hands-on experience
- Feedback that measures and evaluates the users' performance
- On-site guidance and support
- Having a well-designed visual workspace to reduce issues such as divided attention

Additionally, the idea of adapting different AR displays to various stages of training and service is something that should be considered more broadly regardless of industry. The following table will illustrate the pros and cons of using each display in the three areas of training and service identified in the discussion of this thesis: pre-learning where the technician would be on their own, classroom training where the technician would be with trainers working by machines, and on-site service where the technician could be at any or multiple facilities. The table can be used as a guide for future work at this medtech company or for other settings with similar needs, issues or goals.

Table 1

Pros and Cons of Different Displays in the Three Areas of Training and Service

		Pre-learning	Classroom training	On-site Service
HMD	Pros		•Tags and identifies parts •Overlays technical documentation •Offers hand-on training •Supplements lectures •Mobile •Hands free	•Measures performance and sends feedback •Tags and identifies parts •Overlays technical documentation •Mobile •Hands free
	Cons	•Not applicable*	•VAC	•VAC •Power source •Connectivity •Sensitive to lighting conditions
HHD	Pros	•Offers hands-on training •Supplements text learning material •Mobile	•Tags and identifies parts •Overlays technical documentation •Offers hand-on training •Supplements lectures •Mobile	•Measures performance and sends feedback •Tags and identifies parts •Overlays technical documentation •Mobile
	Cons	•Connectivity •Sensitive to lighting conditions	•Requires hands to operate	•Requires hands to operate •Power source •Connectivity •Sensitive to lighting conditions
SAR	Pros		•Interactive training •Recreates large custom made machines •Tags and identifies parts •Overlays technical documentation •Offers hands-on training •Supplements lectures	
	Cons	•Not applicable*	•Surface-based distortions	•Not applicable**

*User most likely does not own AR device
**AR equipment could not be set up on-site

Finally, when considering future work the trainers mentioned one of the biggest issues for them is having the time and energy to create and develop these ideas and applications, and that is what would be required for the future development of AR-based training and application. The AR authoring procedure is the most challenging step, because usually maintenance experts are not IT experts (Havard et al., 2016). This was also the experience of the author in trying to develop an AR application using software designed for anyone to create AR experiences. While these websites and software programs are designed to function for beginning or professional designers it still requires a great deal of time and effort to learn, create, and test each project.

11.2 Bottom Line

The technology and authoring of AR applications are still in the beginning stages and may not be accurate enough for certain tasks, but the wide availability of HHDs, such as Smartphones and tablets, and the fact that several large companies are investing in AR development and working to produce higher performing devices is bringing AR experiences closer to a larger market. Likewise, this study has shown how each AR display can currently be employed in different learning phases and service, and that AR-based training and guidance applications offer many useful and beneficial features that can be developed at this medtech company and other settings as well.

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