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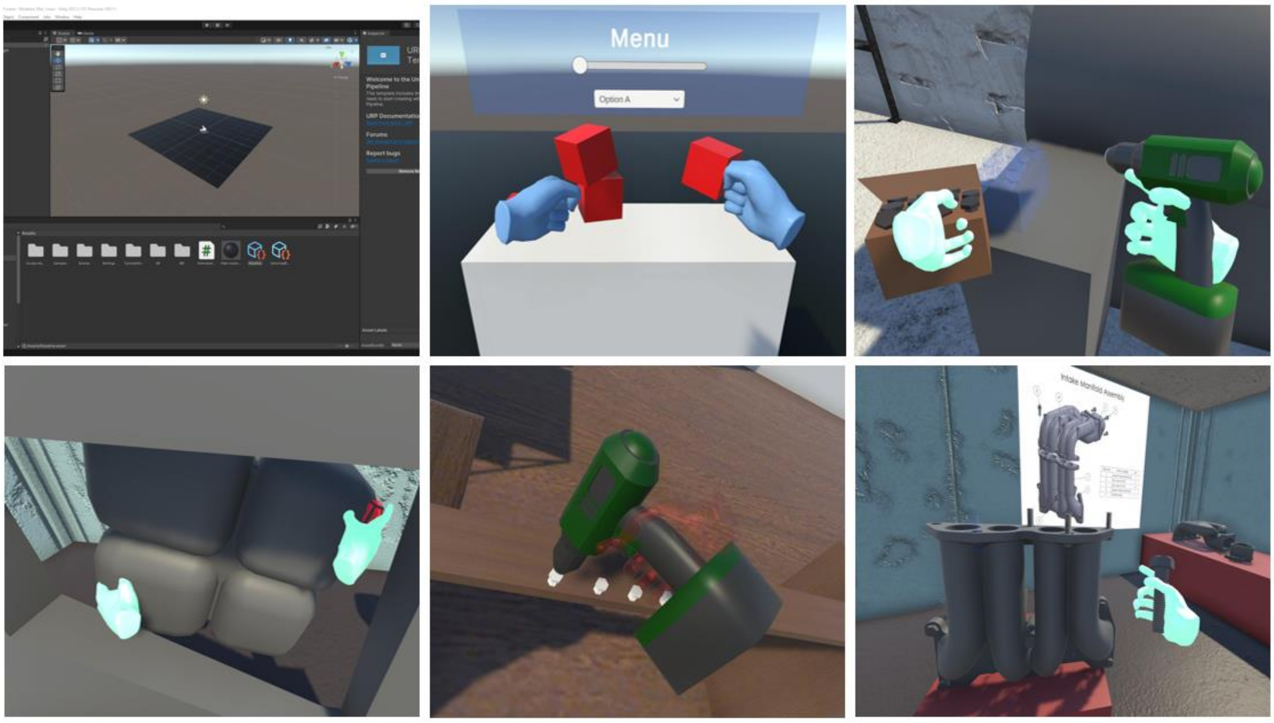

Method to create XR-supported work instructions

Taking the step toward a more sustainable plant

Master's thesis in Product Development

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
www.chalmers.se

Master Thesis 2023

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Cover: The image shows different stages in learning VR in Unity. The image is meant to show what it can look like without spoiling which scenarios were chosen for development.

Gothenburg, Sweden 2023

Abstract

The manufacturing industry is striving to keep up with Industry 4.0, driven by the advancements in digital technology. One area of potential is XR based work instructions, which aims to mitigate the need for complex paper instructions. Currently, there are no standardized ways of developing digital instructions even though XR has proven to be useful for this purpose. This project is conducted at Volvo Cars in Torslanda, and the aim is to identify and test scenarios where XR could replace or complement traditional instructions to identify key principles when developing XR instructions.

The methodology used follows the traditional product development funnel in order to identify the best scenarios for these types of instructions. Unity and HTC Vive were chosen as the development platform for creating the scenarios, and subsequent testing in the form of qualitative interviews with experts in manufacturing and XR.

The result of the thesis is the identification of scenarios where XR instructions could be implemented and a set of principles to keep in mind for future development of XR instructions. In the future, these principles might be used to improve development time and ensure higher quality.

Keywords: Industry 4.0, XR training, XR principles, Virtual Manufacturing, Instructions.

Acknowledgments

We would like to express our sincere gratitude and appreciation to the individuals who have provided invaluable assistance and support throughout the completion of our master's thesis. Firstly, we extend our heartfelt thanks to our supervisors at Chalmers, Xiaoxia Chen and Hao Wang, for their unwavering support during the entire project. Their expertise and mentorship have been crucial in shaping the direction of our thesis. We would also like to acknowledge and thank our examiner, Björn Johansson.

A profound thank you goes to the remarkable support we received from Volvo Cars, starting with our supervisor, Puranjay Mugur. We would also like to express our gratitude to Dan Li and Liselott Erixon for enabling the realization of this master thesis. Special recognition is due to Claes Björklund, Magnus Gustavsson, Alexander Andersson, Henri Hansson and Ledwa Aljoscha from Volvo Cars, as well as Malin Anker from Chalmers for their exceptional support in both learning and utilizing XR technologies. Furthermore, we extend our appreciation to Magnus Olofsson for his assistance in finding suitable test participants. Additionally, we would like to thank Mikael Johansson for his support in identifying suitable scenarios at Volvo Cars together with other crucial leads. Lastly, we would like to express our gratitude to the rest of the Volvo production team for their warm welcome and supportive attitude.

A big thanks also goes to our expert panel that helped us improve the demos after initial development. The help we got from you at RISE, University of Skövde, Volvo Cars and Chalmers played an important role in delivering as good of a showcase as possible.

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Terminology

AR = Augmented reality

AV = Augmented virtuality

BEV = Battery Electric Vehicle

CAD = Computer Aided Design

HMD = Head mounted display

Launch Specialist = Employee responsible for operator training at Volvo Cars

ME = Manufacturing Engineer creating instructions in correct sequence, fulfilling requirements

PPI = Pixels per inch

PPD = Pixel per degree

R&D = Research and Development

SDK = Software development kit

UX = User Experience

VR = Virtual reality

XR = Extended reality

1 Introduction

Extended Reality is a technology that has taken the world by storm and can be used both to play the newest videogames in full immersion or traveling the world from the comfort of your home. This technology has enabled a lot of opportunities for innovation with some examples being the ability to visualize CAD files in a 1:1 ratio and interact with parts even before they are built. This can all save companies both time and money (Munoz, 2023). XR is also proven to be useful when training operators, something that is done by many of the larger automotive companies such as Audi, Volkswagen, and Renault (Nijland, 2023).

1.1 Background

With the rapid advancements in digital technology, the industry wants to keep up with what is commonly called Industry 4.0. One of the hindrances is their work instructions for operators that are paper-based and in many cases difficult to understand. A possible way to make them digital is by using XR technologies. Currently, there are no standardized ways of creating digital training instructions even though XR has proven to be useful for this purpose. Therefore, there is a knowledge gap regarding which instructions should benefit going digital and what type of digital solution that best fits each scenario. It is also unclear how the instructions should be created and the benefits of each solution that satisfies the user, in this case the operators (Helldén & Karlsson, 2020). It has been discovered that operators of today are supportive of the idea and that the problem therefore lies in the industry, which needs to embrace XR to keep up with industry 4.0 (Asklund & Eriksson, 2018).

1.2 Aim and objective

The aim of this master's thesis is to provide instruction support with shorter learning time and better user experience than the paper-based system. For them to be beneficial for Volvo Cars, they should not take longer time and cost more to develop than what is achieved in form of perceived quality according to the operators. Factors like instruction clarity, the time the instructions they take to follow, and technical errors will be considered.

The objective is to bring up scenarios where XR are deemed useful when training operators and set up recommendations for future work with XR-based instructions. This will be done by presenting what was learned from developing instructions of actual assembly scenarios and from testing them on practitioners within Volvo Cars.

1.3 Research questions

Based on the aim and objective, two research questions were formed. These questions will be answered at the end of the project.

> ***RQ1:*** *During which scenarios do industrial practitioners find it suitable to use XR when training operators in the manufacturing engineering industry?*

This research question aims to discover during which type of operations it is deemed suitable to use XR tools such as AR or VR to support training of new operators.

> ***RQ2:*** *What principles can be learned from developing and testing XR scenarios proposed by industrial practitioners that support future development of digital instructions in XR?*

This research question aims to bring forward important learnings made during the testing phases of the XR scenarios. This covers both the perspective of a manufacturing engineer (ME) designing the instructions, as well as the perspective of an operator who follows the instructions. These principles might be used when taking the step toward more digitalization and paperless plants.

1.4 Delimitations

It is important to acknowledge and address the limitations of this study to ensure a complete understanding of the findings and to inform future research. One limitation is that this thesis will only focus on the setting at Volvo Cars. It will therefore not include any observations outside Volvo Cars. The reason for this is both time constraints and the fact that this thesis is written in collaboration with Volvo Cars. Another limitation is that this thesis is limited to using software and hardware available at either Chalmers or Volvo Cars.

The assembly scenarios tested in XR will be few in number and only within final assembly. The chosen software and hardware will be used both for development and testing, therefore comparisons between different manufacturers will not occur. Since the thesis will utilize already developed software, their limitations need to be accounted for. This includes technical limitations such as using rigid bodies instead of soft and less focus on realism. This is in line with the focus of the thesis, being future development of XR instructions for training.

2 Theoretical framework

This chapter will present the theoretical framework of the report. It starts with a pre-study of the current XR technologies on the market and how they are used. This is followed up by the current application of XR in the industry today. The third part contains a description of Volvo Cars' current way of working with XR technologies and how they train operators today. The theoretical framework will be the backbone that much of the following chapters will rely and be built upon.

2.1 Current XR technologies

Extended Reality (XR) is a term that includes a lot of different technologies which all in some ways are used to change the perceived reality for the user. The technology dates to the 1950’s when a man named Morton Helling patented his *Sensorama*. The Sensorama was large as a cabinet and able to show movies with both sound and other senses such as the feeling of wind and temperature changes. Many of Heling’s ideas helped pave the way for today's XR technologies (Taylor, 2022).

There are many different types of XR technologies with different benefits (Nova, 2018). It is argued that there are 4 different stages when you talk about XR, seen in Figure 1 below. The first one, *reality*, refers to the real world, created by only real objects and places that exist in real life. The second stage, *Augmented Reality*, is when virtual interactable objects are added to reality and viewed by some apparatus such as a headset or a smartphone. The third stage, *Augmented Virtuality*, is a virtual world filled with real objects. According to Nova, however, this does not exist and is only possible in science fiction. The last stage, *Virtual Reality*, is a fully virtual world where both the objects and environments are virtual. These four terms can be categorized under the umbrella term known as *Mixed Reality*.

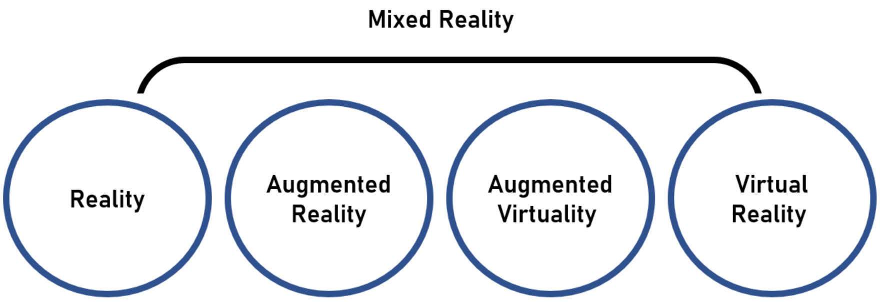

Figure 1: An illustration off the 4Rs (adapted from Nova, 2018)

The following subchapters will present the different technologies more briefly as well as describe the existing hardware and software that supports them.

2.1.1 *Augmented Reality*

Augmented reality means adding something to our reality with the help of some device to create the elution of a physical object. This can be done in several ways such through a head mounted display, using a smartphone, or using something called *light guided AR*. There are several vendors and products on the market which will be described in this subchapter.

There are a lot of different vendors when it comes to head mounted AR displays, all with their different advantages and disadvantages. There are a lot of different factors that need to be considered when acquiring an AR HMD, such as the size and weight of the headset and compatibility with different software as well as important specifications to look out for when choosing an HMD (ST Engineering Antycip, 2020). Table 1 presents several AR products on the market as well as important specifications to look out for when selecting an AR product.

Table 1: AR products on the market (adapted from ST Engineering Antycip, 2020)

AR products on the market	Important specs
Google glasses enterprise 2	Software compatibility
Lenovo ThinkReality 2	Wireless or not
Microsoft HoloLens	Display
Microsoft HoloLens 2	FOV
TCL RayNeo X2	Internal/external position tracking
ThirdEye Razor MR Glasses	Positional tracking
Varjo xr3	PPD
Vuxiz Blade upgraded	Price
	Refresh rate
	Resoultion
	Size
	Weight

There are many ways smartphones can be used for AR purposes. One way to use AR on your phone is by using the screen and the camera, allowing the camera to film your environment around you and put an overlay of visuals on to the video in real time. This technology can be used in games such *Pokémon GO* on your smartphone (Wingfield & Isaac, 2016). In the game, the user can participate in a global AR based game and the main premise is to find Pokémon in the real-world. Figure 2 below shows a Pokémon, a Bulbasaur, on a snowy balcony in Gothenburg.

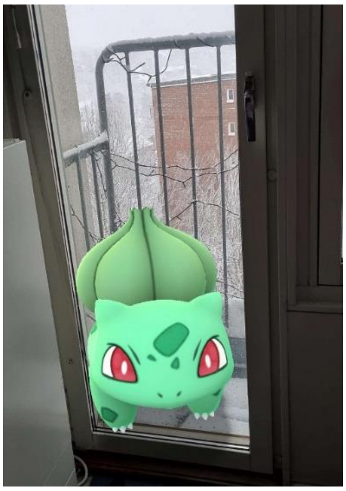

Figure 2: Use of smartphone AR in Pokémon GO

AR can also be used for refurnishing your home with the *IKEA Place* app available on iPhone. Figure 3 shows how a virtual cart can be placed in an office environment with the *IKEA Place* app (IKEA, 2023).

Figure 3: Use of AR in the IKEA place app

2.1.2 Virtual Reality

Due to the full focus on immersion in virtual reality, the two main types of output are Cave VR and head mounted displays. Cave VR is when you have a room with projectors on each wall that project the environment around the user. Head mounted displays on the other hand provide much more immersion and allow for better interaction with the virtual environment. A list of different examples of HMD products currently on the market can be seen to the left in Table 2 below. Since there are so many different variants of VR headsets and use cases, it is important to pick a model that suits the needs of the end-user. Depending on factors such as use case, time spent in the VR environment each day, ergonomics etc. there are different specifications to keep in mind before deciding on a model. These are listed to the right in Table 2 below (ST Engineering Antycip, 2020).

Table 2: VR products and specs (adapted from ST Engineering Antycip, 2020)

VR products on the market	Important specs
Varjo XR-3	Software compatibility
PlayStation VR	Wireless or not
Meta Quest 2	FOV
HTC Vive	Internal/external position tracking
HP Reverb G2	PPI
Pico 4	Price
Pimax Vision 8k	Refresh rate
Google Cardboard	Resolution
	Size
	Weight

There is also the concept of *collaborative VR* where many different people can come together in a virtual environment, each with their own set of HMD and controllers to interact with each other. This allows for virtual meeting rooms with co-operation, something that is in use today with the video game *PUBG* and Facebook's *Metaverse* as two examples (ST Engineering Antycip, 2020).

2.1.3 Hybrid headset

There are products on the market which combine aspects of AR and VR to create something called a hybrid headset. They most often utilize an HMD and examples of this are the *Varjo XR-3* and *Google Cardboard* (Google Cardboard, 2023). This hybrid technology gives the ability to show some objects as virtual while keeping some objects from real life. This allows for more flexibility and use cases.

2.1.4 Software

There is many different software on the market that are either built around XR or have added support for it. Software with support for XR can be categorized into two categories: software originally meant for engineering or modelling purposes and software meant primarily for gaming (Davies, 2022). These are described in Table 3 below.

Table 3: Different XR software and their purpose (adapted from Davies, 2022)

Engineering	Gaming
3D Experience	Unity
3DS MAX	Unreal Engine
3DS Maya	Cryengine
Blender	Steam VR
Google VR	
Amazon	
Sumerian	
Oculus Medium	

When deciding what software to use there are many factors to take into consideration. The first one is the license model each software utilizes, something that varies between being free and open-source, one-time payment, and subscription license. Apart from economic reasons, the license model affects the degree of support possible to get for a software with the more expensive ones usually having a lot of guides both for installation and use of the SDK. The second one is what type of hardware is compatible with each software. Some software is developed directly to be used with certain hardware, while others might allow the use of many different (Davies, 2022).

2.1.5 Hardware input

There are multiple ways to interact with software in a virtual or augmented world. These range from more classic video game controllers to motion tracking, gloves, and voice commands, all explained in more detail.

Motion controllers

The most common way of interacting is to use motion controllers. These come in many different shapes and sizes and are used in everything from *HTC Vive* to *Oculus Quest*. The controllers often come in pairs of two, allowing for interaction with both hands. Usually, they have different buttons for interacting with menus as well as mimicking the opening and closing of hands (Gajsek, 2022).

Motion tracking

Another way of registering movement and interacting with the virtual world is by using motion capture. This utilizes a combination of dots placed on your body together with a camera to capture the users' movements and transfer it to the computer (Eunchong, Gongkyu, & Sunjin, 2022).

Haptic feedback gloves

There is technology able to mimic touch and different forces in the VR environment. This is done with the help of special gloves that can apply force to your fingers. There are different brands that sell this type of technology, two examples are *Haptx Glove G1* (Haptx, 2023) and Teslasuit's *the Glove*. Both examples do similar jobs but with different technologies (Teslasuit, 2023).

Voice commands

Many of the headsets come with an integrated microphone that can be used for both communications online and for interaction with the software. One example is *HoloLens* from Microsoft which uses voice commands. This lets the user navigate through menus and perform actions in AR such as taking screenshots or switching through instructions by only using your voice. Similar commands work in Windows through Cortana (Voice input, 2022). Smartphones and other smart home applications of today such as *Google home* and *Apple's Siri* function in the same way.

2.2 Application in industry

There are many industrial uses for XR in engineering, allowing testing and validating everything from factory planning to products without having to buy expensive equipment. In this chapter the focus will be on investigating what XR technology can bring to the table regarding informing and training operators in the assembly.

2.2.1 AR applications

With AR, it is possible to guide operators through remote guidance. This allows operators wearing AR goggles to be remotely guided through an assembly task by another person located elsewhere, often at a computer. This method of informing scored the highest in a study regarding assembly quality together with video tutorials. However, this technology scored less well in comparison to the more conventional methods (Gong, 2020).

Another use case for AR is described in an article written by Liang Gong et. al. They describe a case where AR is used to give additional information for people working in warehouses performing lots of picking in their work. The information displayed to the warehouse worker helps them navigate and find the right thing with the help of colorful graphics and text. By using an HMD, they also free up both hands compared to using a phone or similar navigation object (Gong, Fast-Berglund, & Johansson, 2021).

The last example of AR is Light guided AR, used to instruct operators with the help of a projector and image recognition. By projecting the light on a desk, the program can create visuals that show where to place parts, and in which order they should be mounted. It can also count down when performing tasks during a specific time frame, usable for gluing or whipping a clean surface. This system can also recognize if the operator does something wrong and alert the operator. A potential limiting factor with this technology is that the operation needs to be conducted on the table itself or on another flat surface because of the projector. The technology can also only display information in 2D (LightGuide, 2019).

2.2.2 VR applications

VR can be implemented in many different parts of the industry and is a useful tool for operator training. It has been tested when training operators in engine assembly. Since complex instructions are easier to remember when participating live in a simulation than just observing them in the form of videos, written instructions etc. the training quality will improve and less mistakes will be made. In addition, using VR can compensate for physical training by tracking motions when training requires motor skills (Schroeder, Friedewald, Kahlefendt, & Lödding, 2017). This is further proven in other studies where they state that VR can become a powerful tool as it improves operators' skills, knowledge, competence, awareness, preparedness, and safety behavior (Talabă & Angelos, 2008). Specifically, awareness and safety behavior are prominent in the industry. It is argued that through VR, the risk of hurting yourself is eliminated while simultaneously enhancing the realism of the training.

VR also allows the use of *remote guidance*. Just like in the previous mentioned example with AR, it is also possible to train operators in a virtual environment from a separate computer or using collaborative VR. This way, the operator never has to leave the virtual world or worry about navigation through menus. Remote guidance seems to score high in terms of completion rate and quality but takes longer time compared to many different methods (Gong, 2020).

2.2.3 Recommendations from literature

Different studies, like (Nijland, 2023) and (Gong, 2020) have been carried out regarding XR applications in the industry. It is argued that in a future with more product variants with increased customization, the operators will become even more challenged. On top of that, the operator needs training in how to use the XR equipment before learning assembly operations, since the more familiar you are with XR tools the better the results. The demos take a lot of effort to develop, including converting CAD files and setting up the environments. XR is therefore only recommended for highly complex operation instructions or operations with major safety requirements (Gong, 2020).

There is also research into what type of XR hardware and software is to be used for what type of operations. A previously mentioned study by Eunchong et. al, contains demos of real assembly operations. There they recommend using the Unity engine together with a VR Interaction Toolkit to enable *HTC Vive* or *Oculus Rift S*. The scripting language used was C# that runs in Microsoft Visual Studio. A desktop PC is also recommended with high specifications to run everything properly (Eunchong, Gongkyu, & Sunjin, 2022).

2.3 Case introduction

The chapter explores Volvo Cars as a company, how the current operator instructions are designed, how operator training is performed as well as how Volvo Cars is currently using XR in their work within final assembly. The chapter ends with a brief view of how competitors are using XR for similar applications.

2.3.1 Volvo Cars

Volvo Personvagnar AB, or Volvo Cars in English is a Swedish manufacturer of vehicles. It was founded in 1927 and the main headquarters is in Torslanda in Gothenburg. Volvo Cars manufactures station wagons, sedans and SUVs and their main marketing argument is safety.

They currently have production plants in Sweden, Belgium, China, Malaysia, India, and USA. The focus of this thesis is mainly on the Torslanda plant where they currently manufacture the V60, XC60, V90 and XC90.

2.3.2 Current instructions

From a visit to the Volvo factory in Torslanda, guided by an expert in digitalization, insights into the operator’s work were gained to get a better understanding of how the instructions are currently presented. It was discovered that in the current state Volvo Cars have paper instructions in their factory placed right beside the station in a folder. The operators do not have time to read them due to the intense pace of the factory where they build approximately one car per minute. Some stations have developed their own simplified instructions and are hung on a wall which often clarifies an important step for the operator. This is not standard in the factory but instead something created by that station's team leader or someone similar.

The factory currently has two different models in production, the XC60 and the XC90, but there are a lot of different variations of the same car. Some potential variations are the size of the engine, whether it has skylight or not and the materials of the seats. Therefore, the operators need to be able to work on different car types on the same production line. The specifications of the car are displayed in paper form, hanging from the trunk of the car. In the instructions it is described how to do with different car models. In general, the instructions can only be read during the break due to the earlier mentioned fast pace in the factory.

The factory also has many different types of stations where most are placed on one of the assembly lines which moves the part from station to station. There are also preassembly stations that stand still where subassemblies are put together and later transported by the logistics team to one of the main assemblies. One exception from the paper-based instructions is the pick by light system that helps the operators to pick the right objects with the help of a green light that lights up which parts should be picked.

2.3.3 Operator training

To learn about the current operator training at Volvo Cars, an interview was held with one of the launch managers. It was discovered that Volvo Cars has an internal training model within final assembly called the *5-step model*.

The newly employed start off with an introduction to the company and the plant. This is followed up by safety guidelines and routines together with some basic assembly training. When that is finished, the operator gets installed in either A, B, C-shop, or logistics to receive training for that specific plant. The fourth step is the last for training and development. Here the operator receives training both offline and online together with education in safety. The fourth can also be used for operators changing from one station to another. Finally, the operator gets validated through testing. This step should include specific tasks that are performed over time such as a specific number of cycles or cars built etc. This is verified from a safety, quality, and performance perspective.

2.3.4 Current work with XR

Currently, Volvo Cars has several XR labs where they utilize different technologies for research and testing purposes. These were visited to gain insight into how Volvo Cars currently work with XR. For final assembly, they have a *mixed reality lab* where they test and perform ergonomic simulations for assembly, both with VR and AR. In both cases they have different props that can help sell the illusion of a virtual space. One common prop used in both VR and AR applications are aluminum scaffoldings that are used to create barriers in the real world which correspond to the virtual environment. Equipment currently in use is HTC Vive for VR applications and HoloLens 1 and 2 for AR applications. Tests that require high immersion with great graphics utilize HoloLens 2 in Unreal Engine. HoloLens 1 headsets on the other hand are kept for cases where multiple users are required. This multiuser function is allowed through in-house software. XR is also used in the R&D sector of Volvo Cars for testing everything from fitment to testing and verifying during development. They even have a designated team at Volvo open innovation Arena where they test new upcoming technologies for Volvo Cars.

2.3.5 Competitors working with XR instructions

There are many competitors that work with VR instructions to assist their operators during training. In his article, Nijland describes how different fields use VR for training. The first example is that Renault uses VR to conduct safety training with focus on work postures. He also mentions that Audi currently is developing an SDK for creating VR training environments which will enable developers to create training environments without the need of knowing how to program. This is possible by creating standard building blocks with different actions which can be put together to create more advanced sequences. One building block could for example be grabbing an object. Volkswagen have also developed training sections for operators regarding assembly as example and they have a standardized way of working with the operator having the headset on and having an instructor instructing the operator on what important during the training session (Nijland, 2023).

3 Method

This chapter explains how the thesis has been carried out. As seen in Figure 4, the process began by performing a pre-study to get knowledge of the current technologies on the market and how they are used today in the industry. The results are seen in the theoretical framework. The following step was to find scenarios from the industry to replicate in XR. This included a stakeholder analysis, setting up a requirement specification and evaluating the scenarios with selection matrixes. When the scenarios were selected, the development phase began where the software was learned and used to develop demos of the chosen scenarios. In the testing phase, the qualitative interview questions were formed and practitioners within Volvo Cars got to test the demos. The results part contains all findings done throughout the thesis and connects back to the research questions where the usefulness of XR is presented along with other findings and recommendations.

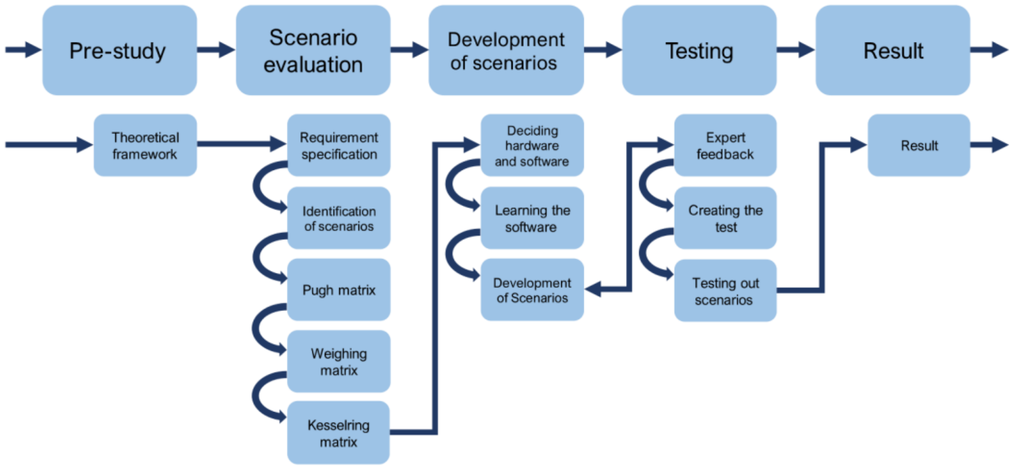

Figure 4: Illustration of the methodology leading to results

3.1 Stakeholder analysis

To get a better understanding of who the main customers for this project are, a stakeholder analysis was performed. This was done by reading literature on the topic and reaching out to people within Volvo Cars with knowledge of manufacturing and training of operators. A visit to the assembly plant was also conducted to get more firsthand experience of the stakeholders and their needs.

The stakeholders were later used to set up a customer analysis with a customer needs list. These customer needs were later used when setting up the requirement specification as well as when evaluating which scenarios to create in XR.

3.2 Scenario identification

The first step was to find potential scenarios where XR could be used to teach or inform operators in the factory. This process began by asking the identified stakeholders if they had any scenarios where they deemed XR as a good tool for improvement. Ideally it would have been best to get input from the operators themselves during this step but due to the limited accessibility to contact operators, it was not possible. The group had to settle with the next best thing which in this case was secondary users from the stakeholder analysis. This group of people consists of everything from Simulation engineers to Central Manufacturing engineers. This group of specialists are in the field of production and are more than capable of identifying suitable scenarios for XR. The process of contacting these individuals was a combination of email contact and different meetings with different spokespersons from the different areas within Volvo Cars.

3.3 Scenario evaluation

Since this is a master's thesis with limited time, it was not possible to create and test all of them given the time frame. Therefore, only the best suited ones were explored further. The cases will be funneled down using standard decision-making matrices, following a standardized product development funnel (Ulrich, Eppinger, & Yang C, 2019). The down selection process will be done in three steps, firstly a requirement specification then two iterations of Pugh matrices and finally Kesselring matrix combined with a weighing matrix.

3.3.1 Requirement specification

To evaluate and down select the scenarios, some requirements were needed. These requirements will be based on customer needs and requirements. The customer needs together with learning made along the way will therefore be used to set up a requirement specification for the demos. This includes both what the demos should include, how they should function as well as which types of scenarios that benefit a digital solution. This is to ensure high customer value for the instructions and not spend time developing something that is not needed.

3.3.2 Pugh matrix

After defining the requirements for the scenarios, it was time to evaluate the twelve defined scenarios. The first evaluation method used was a Pugh matrix which compares solutions against one randomly selected reference. In Table 4 an example of a Pugh matrix can be seen with all requirements listed in the left most column. In this case, scenario A has been chosen as reference, visualized in red. In this example, requirement 1 for scenario A is compared to requirement 1 for scenario B. Since scenario B performed worse than scenario A, it is given a minus. The two other possible scores are either a plus if it performs better and a zero if they perform equally. The score is then summarized, and the scenarios are ranked from best to worst.

In this project, two iterations of the matrix were conducted in order to ensure that the solutions that are eliminated in the first step of the evaluation are the least suitable. Since the Pugh matrix does not consider the importance of the requirements, it is recommended to iterate at least twice to minimize the risk of eliminating potential good scenarios by mistake.

Table 4: Pugh example

Criteria	A	B	C	D
Requirement 1	ref	-	-	0
Requirement 2	ref	+	-	0
Requirement 3	ref	-	0	+
Sum +	ref	1	0	1
Sum -	ref	2	2	0
Total	ref	-1	-2	1

3.3.3 Weighing matrix

Before setting up the Kesselring matrix, the requirements had to be weighed in order of importance. This was done through a weighing matrix. In the matrix, every requirement was put up against each other. If one requirement was deemed more important than the other, it was marked with a one, otherwise it was marked with a zero. The score is summarized, as seen in Table 5 below where requirement 3 is shown to be most important with a score of 2. The scores are then converted into relative scores which will be used as multiplying factors in the Kesselring matrix.

Table 5: Weight matrix example

Criteria	Requirement 1	Requirement 2	Requirement 3	∑	∑rel
Requirement 1	-	0	0	0	0
Requirement 2	1	-	0	1	0,1
Requirement 3	1	1	-	2	0,2
				Tot	Tot
				3	0,3

3.3.4 Kesselring matrix

The final step in evaluating the scenarios was the Kesselring matrix. Here, the scenarios are scored for each requirement from one to five, seen in Table 6 as *v*. That score was then multiplied with the weight factor *w* to get a weighed score, *t*. The final score was summarized and the one with the highest score was marked in green. In the example below, scenario G won with a score of 2.3. Compared to the Pugh matrix, the Kesselring matrix takes the importance into consideration.

Table 6: Kesselring example

		Ideal		D		E		G		H	
Criteria	**w**	**v**	**t**	**v**	**t**	**v**	**t**	**v**	**t**	**v**	**t**
Requirement 1	0	5	0	3	0	3	0	4	0	1	0
Requirement 2	0,2	5	1	3	0,6	2	0,4	4	0,8	1	0,2
Requirement 3	0,3	5	1,5	3	0,9	5	1,5	5	1,5	1	0,3
Score			2,5		1,5		1,9		2,3		0,5
Average		5	0,83	3	0,5	3,33	0,63	4,33	0,77	1	0,17
Ranking					3		2		1		4

To minimize the risk of bias toward one or more solutions, the level of fulfillment, *v*, was listed in 5 tables, seen in Table 7 below. Every point from 1 to 5 was defined to keep it the same for every scenario. Without this, there is a risk of evaluating differently, potentially giving higher score to ones own favorite scenarios.

Table 7: Levels of fulfillment

	Shall contain many steps	High step variety	Ambiguous instructions	XR feasibility	Short XR development time
Score:					
1	Only one step	All steps are the same	Easy pick and place	Technology not ready	More than one week
2	Two steps	One step variation	Some guidelines to remember	Significant coding skills	Around a week
3	Three steps	Two or more variations	Specific order, use of tools	Experience needed	A couple of days
4	Four steps	Different assembly types	Weird angles, hard to see or understand	Doable after a course	One full day
5	Five or more steps	Varying steps of different types	Ambiguous, hard to visualize on paper	Everyone can do it	Around 4 hours

3.4 Development of scenarios

This chapter aims to describe the development of the XR scenarios. It begins with explaining how the selection of software and hardware was done, followed by how the software was learned. The last subchapter explains how the final demos were developed.

3.4.1 Deciding hardware and software

With the final scenarios now identified, it was possible to properly choose hardware and software for the rest of the project. The decision was based off what was deemed most suitable for the specific scenarios within the given timeframe. Previously documented findings from the pre-study were also considered to support the choices made.

As explained in the pre-study, some factors were important to take into consideration when choosing software. The most important ones are the support for the chosen XR-type, the license model used and the amount of previous knowledge within the company. Since the chosen scenarios turned out to be VR-cases, it was important to find software that supported VR, thus leaving AR out of the picture. In terms of licensing and previous knowledge, there were two candidates that stood out, Unity and Unreal Engine 4. Each software is being used at Volvo Cars and there was lots of documentation on the internet in forums and on YouTube.

The final decision fell on Unity due to the easier learning curve, more knowledge within Volvo Cars and the possibility to get support from teachers at Chalmers. Unity also has a large user base and there are a lot of tutorials and learning materials for both beginners and experienced users. This includes Unity’s own learning platform *Unity Learn* but also a lot of third-party material on both YouTube and different web forums. Unity also has different stages of licensing, varying from free ones to industry licenses, making it accessible for all types of users. Unity was also recommended by industrial practitioners from the Open innovation arena at Volvo Cars. Unity was also recommended due to the large amount of documentation on the internet. Volvo Cars also has a history of co-operating with Unity and therefore already owns Unity licenses.

When deciding upon the hardware, the choice of software had to be considered since they need to be compatible with each other. Since the chosen scenarios are most suitable for VR, it was decided to start in that end with an HMD. As described in the pre-study, there are many different HMDs on the market with a lot of different specifications. The ones deemed relevant in the end were HTC Vive, Oculus Quest, and the Varjo XR-3 since they were all compatible with Unity and available at either Volvo Cars or Chalmers. Since the thesis focuses more on the feasibility of using XR and the demos being more proofs of concept, visual fidelity is not prioritized. This meant the Varjo XR-3 was scrapped early on due to it being too advanced for these demos.

The final decision for the hardware stood between the Oculus Quest and the HTC Vive, which both have similar technical specifications. They both support Unity and have a similar amount of learning material on the internet. In the end, HTC Vive was chosen since both Chalmers and Volvo Cars already own a set of equipment. With HTC Vive already being available at both locations, more support would be available and opened the possibility of working from Chalmers when necessary. When it comes to the controllers, the decision fell on using the standard ones who comes with the HTC Vive. Figure 5 shows the headset and controllers used throughout the project.

Figure 5 HTC Vive HMD and standard controllers

Other options such as haptic feedback gloves and finger tracking were scrapped to avoid compatibility issues with Unity and to save development time. A plugin was found that mapped the HTC Vive controllers to virtual hands, allowing some realism.

3.4.2 Learning the software

The path to learning Unity began by following a free video course in 9 parts on YouTube (Munoz, 2023). This included both the basics of Unity itself, how to navigate the software, as well as a brief introduction to Microsoft Visual Studio. A package called *XR Interaction Toolbox* was used to give Unity support for XR controllers and HMD. Basic features such as the ability to move around and use your hands were set up through C# scripts written in Visual

Studio. The buttons on the side of the controllers were mapped to a *grab* function, allowing the user to pick up objects with immersive hand animations. The trigger on the back of the controllers were mapped to a *use* function, allowing interaction with objects. The touchpad on the left controller allowed the user to walk around, apart from moving around physically in the room. The touchpad on the right controller enabled rotation, like a joystick.

The learning process is illustrated in Figure 6, starting with an empty space with a light source and an empty plane. The first step was learning how to interact with objects as well as picking them up and throwing them around. It was also discovered how to create an interactable UI containing basic settings such as a slider and a drop-down menu, seen in the second frame.

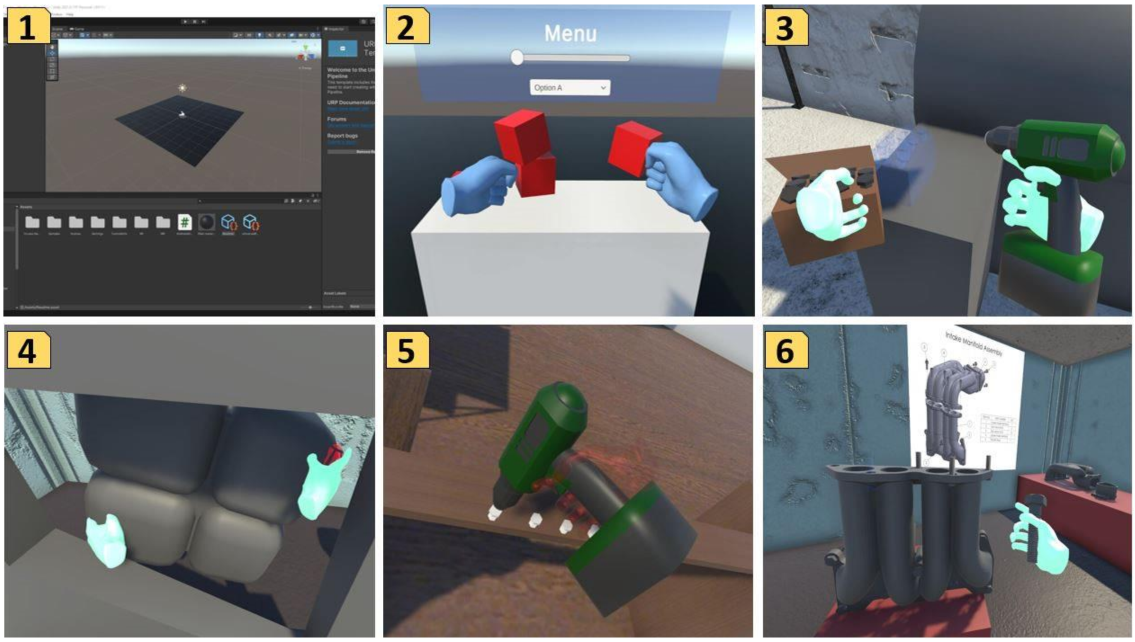

Figure 6: Visual representation of Unity learning path

Early in the process, it was realized that writing every single interaction through code would become a tedious and time-consuming process. As discovered in the pre-study, competitors such as Audi develop software that will simplify this process by allowing visual programming with blocks. This led to the discovery of a plugin called *VR Builder* which allowed visual programming for VR in Unity. This plugin is available for free in the Unity asset store and supports many different types of VR. An example of this is illustrated in Figure 7 below, where a drilling sequence is showcased.

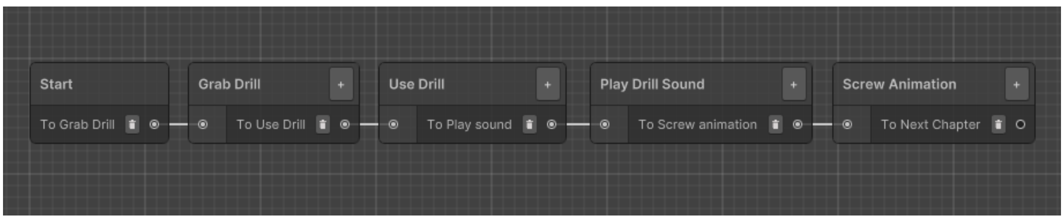

Figure 7: Drill sequence with sound

This made it easy to create interactable tools, such as a power drill and make pick and place operations where objects could be snapped in place. The third frame in Figure 5 shows a box with screws that can be placed in a blue snap zone.

Since there is no limit to how detailed and immersive you can go in Unity XR, demos mimicking real scenarios were created to see if the current knowledge was enough. All of these training environments are seen in Appendix A. The fourth picture shows installation of a box that is guided through a small hole. The box did not fit straight on and had to be tilted in a specific angle to mimic a real scenario of a subwoofer installation. To prepare for screw assembly operations, a power drill with working sound was created. This is visualized in frame 5 together with a plank and four screws, all entered by hand and tightened by the power drill.

Frame 6 in Figure 6 illustrates the final test where instructions were experimented with. In this test, assembly instructions are hung up on a wall together with voice lines telling the operator what to do. Highlight was also experimented with where each screw and their installation position were highlighted in red. The learning continued all throughout the thesis project in parallel to setting up demos for the chosen scenarios.

3.4.3 Development of scenario D Assembly of door panel

The first demo that was developed was the door module. Development first began by getting correct CAD-models from the manufacturing engineer. The door was then split into different parts, downscaled, and converted through Pixyz. In Unity, a room was created with a rack for the loose door modules and the doorframe was placed near the modules. Knowledge from the learning phase was used throughout the whole process. Snapping of the door module into the door frame was done using snap-zones and the fastening of the 14 bolts was made with animations just as in the learning phase. The only difference here being added highlights for which screw to be tightened and the use of an actual Volvo Cars power drill, also imported through Pixyz, see Figure 8. One thing that had to be improvised was the cable that was supposed to be inserted through a hole in the door module. As described in the pre-study, flexible parts were hard to create in 3D. After much tweaking, it was decided to lock the cable in all axes except for *X*, making the cable only movable to the left and right but keeping it stiff.

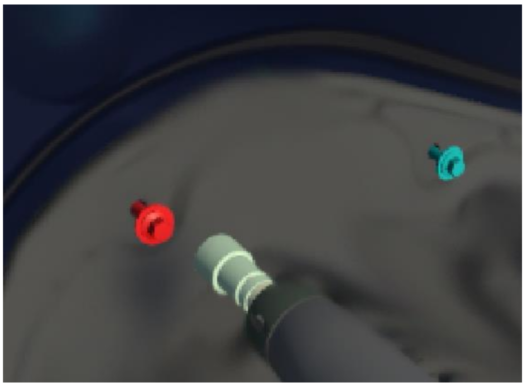

Figure 8: Highlighted screw soon to be tightened

The instructions were given to the user both by integrated text-to-talk and by floating textboxes. By using the activate and deactivate functions in the coding blocks, the text could appear when needed and hid when the step was completed.

3.4.4 Development of scenario G Assembly of leveling sensor

The first step for this demo was to get in contact with a simulation engineer to get hold of correct CAD-files. Pixyz was used to downscale and export the files into Unity, see Figure 9. The rear axis was placed on a platform with the leveling sensor in front. The first step was making the upper hook on the sensor snap to the upper hole in the rear axis. This was done by using snap-zones. To make it more realistic, the snap zones were made small and tight and placed on the hook and in the hole by tweaking the box-collider. The upper screw was tightened with a Volvo Cars power drill in the same way as in the other demo, also with a highlight on the screw. The lower part of the sensor was kept as a separate part, as a child, to make it moveable in the aligning step. This was done by locking rotation and translation in all axes except for rotation in the x-axis.

The bottom screw is then tightened, just like the other screw steps. Instructions were done through text-to-talk and floating text boxes that were activated when needed and hid when the step was completed.

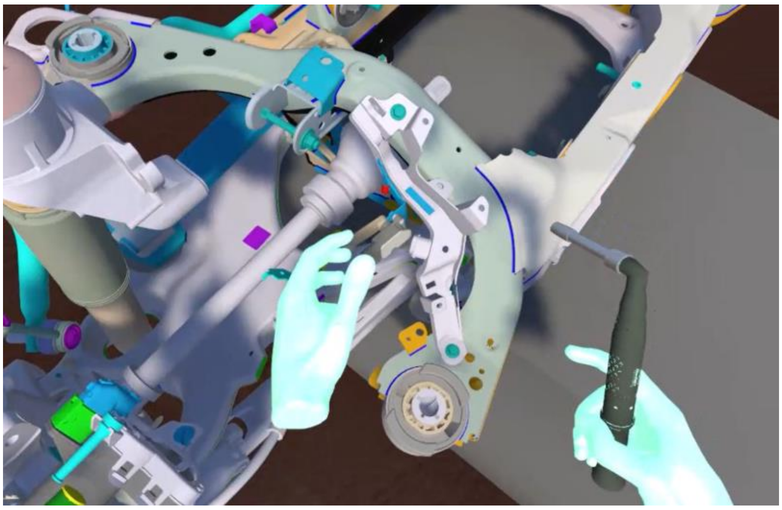

Figure 9: Sensor in place with upper screw highlighted in red

3.5 Testing of demos

This chapter describes everything related to the testing of the demo instructions, starting with feedback from experts in the field of virtual manufacturing and interaction design. This is followed by a description of how the interview questions were designed as well as how the testing was carried out. The last sub-chapter describes how the collected test data was sorted and evaluated.

3.5.1 Expert feedback

With the two demos ready to play, it was decided to get some feedback from experts in the field of virtual manufacturing and user experience before testing them on the practitioners at Volvo Cars. This was done by showing them recordings of the current versions of the two demos to gain knowledge of how to inform the operators in the best ways as well as to increase user experience. The experts were comprised of researchers from RISE and the University of Skövde. They are currently part of a project called PLENUM together with Volvo Cars related to digital manufacturing (PLENUM, 2022). Representatives from Volvo Cars were also interviewed in the form of one method developer and a digital strategy manager, both with extensive knowledge of XR. A professor in user experience (UX) was also consulted to ensure the quality of the UX design. All input was gathered through shorter interviews and the transcripts can be seen in Appendix B. Finally, a second Gemba walk to the assembly plant was conducted to see the real operations and compare them with the scenarios created. Much of the expert feedback and impressions from the factory was implemented in the final iterations of the demos.

3.5.2 Testing and question layout

The testing was done by letting industrial practitioners test the demos in VR themselves. Beforehand, they were given a short introduction to the equipment and the scenarios they were supposed to test. The ideal scenario was always to make sure they could complete the demo without any support, but guidance was provided when needed.

After having completed the demos, they were interviewed using a set of qualitative questions, seen in Appendix C. The questions were divided into four categories with the first one being *intro questions* which mostly aims to characterize the interviewed and at the same time act as an icebreaker for the more in-depth questions in the coming categories. The second category is called *result* and focuses on if the demo worked as intended and if there were problems executing the demo. The third step of the question was *information* which focuses on whether the right information was presented and if it was presented at the right time. The fourth category is called *suitable tool* and focuses on figuring out if VR is a suitable tool for the scenarios. The goal was to get as valuable feedback as possible before writing the recommendations for future work with digital assembly operations.

3.5.3 Evaluation of testing

In total, 18 people were tested upon during 6 separate sessions. The transcribed interview data, seen in Appendix D, was converted from interview transcripts to more comprehensive data through an affinity diagram. The method used is called affinity mapping, also known as the K-J method, explained by Boogaard (Boogard, 2023). The input from the interviews was written onto digital post-it notes and sorted into categories. Ideas similar to each other were placed closely together in a cluster to draw conclusions regarding importance and frequency. Figure 10 shows how the sorting process looked like. In total, 141 post-it notes were sorted into 2 main categories, *Aim of XR instructions* and *User Interaction.* Appendix E and F show the two categories with all post-it notes readable.

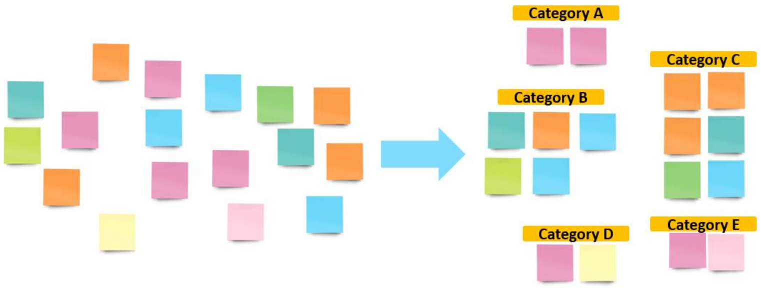

Figure 10: Example of how an affinity diagram is conducted

The post-it notes were color coded regarding which type of stakeholder who said what. Since the launch specialists have experience as operators, they were regarded as primary stakeholders and colored two shades of green, seen in Table 8. This was to further differentiate the input in terms of importance with the primary stakeholders holding most weight.

Table 8: Test participants and their color

5 Launch specialists
3 Launch specialists
4 Shop floor engineers
1 Digitalization expert
1 Manufacturing and 2 simulation engineers
1 Simulation engineer and 1 VR expert

With all information sorted, conclusions could be drawn regarding what was requested by many stakeholders and with which competences. These were formed into principles important to keep in mind when designing digital XR training instructions.

4 Results

This chapter presents all results from the thesis. The different sub-chapters bring up the results from the methodology and lead to the two research questions. As visualized in Figure 11, it starts with presenting the identified stakeholders and their needs, followed by all identified scenarios, leading up to research question one. The second research question will be answered after presenting the evaluated scenarios, the development of these and the results from the testing.

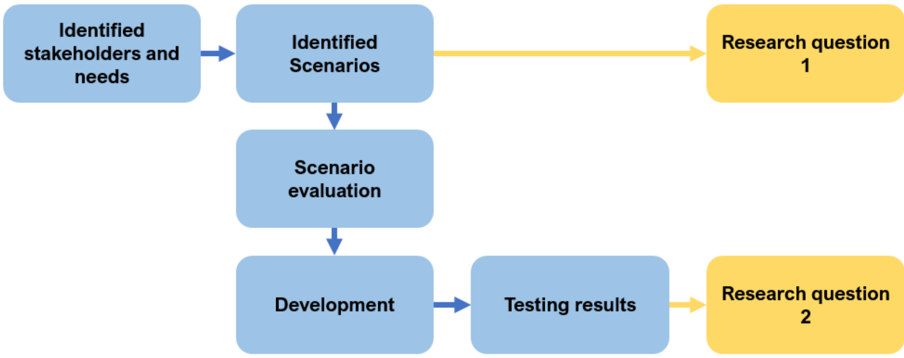

Figure 11: Road map of the results leading up to the research questions

4.1 Identified stakeholders and needs

From the stakeholder analysis, it was discovered that the primary stakeholders were the operators working at the assembly plant. The secondary stakeholders are the launch specialists responsible for releasing new cars in the plant, together with employees working with creating instructions and operator training. On behalf of the operators, it was understood that they require instructions that are easy to follow. Another aspect to consider is the development time of instructions, which should not take longer than it does today. The same goes for the XR-training itself, which should not be too complicated to learn.

From the literature study it was learned that for XR instruction to be beneficial, it should be exclusive to complicated instructions involving many steps. Otherwise, it might take more resources to develop and set up in XR than it is beneficial from an understanding point of view (Gong, 2020).

The tertiary stakeholders of this project are people responsible for maintaining the XR equipment and the computers. When talking with the people working both in the HoloLens room and the Open Innovation Arena it was learned that XR often involves a lot of hassle. Problems such as computers not working, equipment failing and licenses not working properly are things to keep in mind if a company decides to become more digital. All stakeholders and needs are listed in Table 9.

.

Table 9: Stakeholders and their needs

Stakeholder	Participant	Needs
Primary	Operators at Volvo Cars	Easy to follow
Secondary	Employees creating instructions Employees responsible for operator training	Quick develop time for instructions Short start up period for learning XR High instruction complexity
Tertiary	Maintenance of IT and XR	Easy to maintain
Customer	Volvo Cars	Move away from paper based

4.2 Identified scenarios

The result of speaking to the secondary stakeholders was a collection of twelve different scenarios named from A to L. These scenarios are predominantly VR scenarios with only a few being proposed for AR or both. Down below, all the twelve scenarios are described briefly together with where the scenarios were proposed from and with example pictures. The pictures are generated by the free AI-generator DALL-E and manipulated manually in Adobe Photoshop. The reason for this being due to company secrets and most scenarios coming from unreleased cars.

Scenario A - Subwoofer assembly

Proposed by: Simulation Engineer

In this scenario, a subwoofer should be inserted in the trunk of an SUV. The subwoofer should sit on the right side of the trunk, just above where the spare wheel is in some cars, see Figure 12. The operator starts by leaning into the trunk with the subwoofer and snapping it in place by adding a little force on the clips. It is finished by fastening the screws with a power drill. This case has already been tested in AR, and the proposal was to try the same thing in VR.

Figure 12: Car trunk with a mounted subwoofer highlighted in red (DALL-E and Adobe Photoshop)

Scenario B - Assembly of battery to car
Proposed by: Simulation Engineer

This scenario is about connecting a battery pack on the bottom of a BEV. This is to be done by fastening 14 bolts with the help of a power drill, see Figure 13. It originates from an ergonomics case where the operator needs to hold the tool in a specific angle and stand in correct position when fastening. The scenario could either be done in AR or VR.

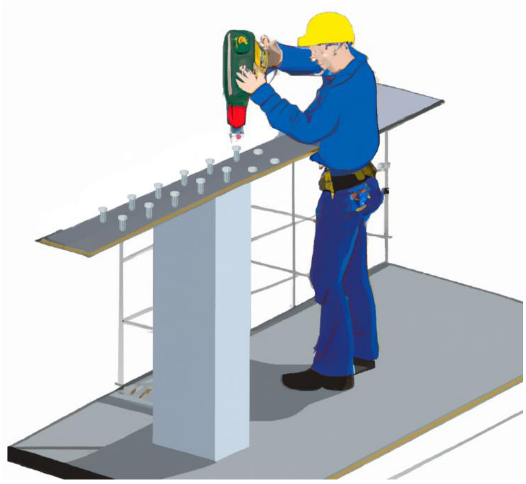

Figure 13: Operator tightening screws with a power drill (DALL-E and Adobe Photoshop)

Scenario C - Assembly of electric door module
Proposed by: Central Manufacturing Engineer

For this scenario, an electric module for a car door, see Figure 14. The module contains many different door components and cables that should be inserted in the correct position inside the door frame, snapped in place at the correct positions and then the cables should be managed as well. Here, VR was proposed to teach the sequence and adding another layer of realism compared to the paper instructions.

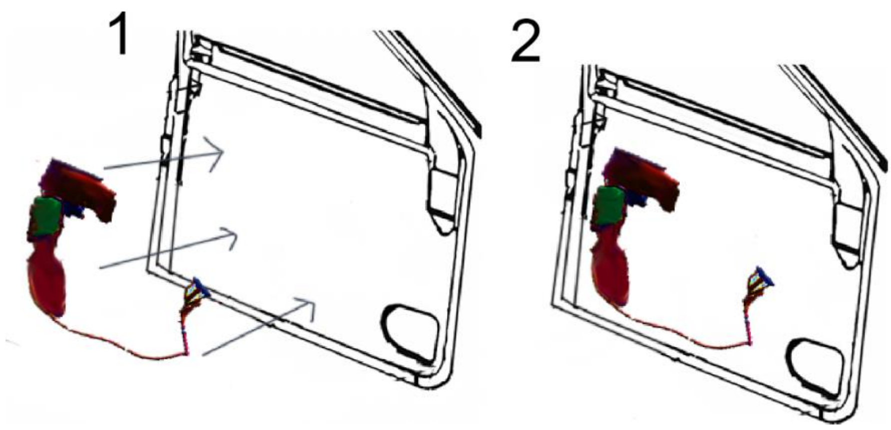

Figure 14: Electric module being inserted into door frame (DALL-E and Adobe Photoshop)

Scenario D - Assembly of door panel
Proposed by: Central Manufacturing Engineer

This scenario is a continuation of the electric module. After that has been assembled, the door panel should be snapped on top to hide the electronics, see Figure 15. After that, a large cable should be pulled through a hole in the upper left corner of the door panel and lastly 14 bolts should be tightened with the use of a power drill. The idea is to teach the operator the sequence before stepping onto the real line.

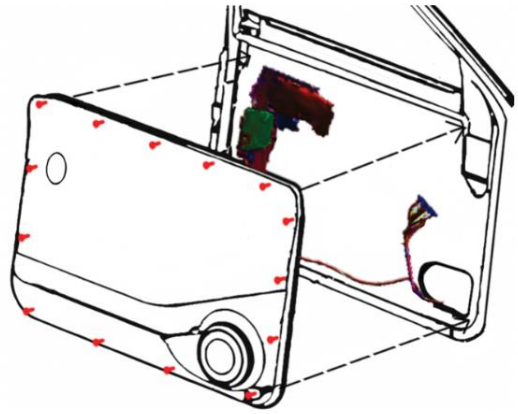

Figure 15: Illustration of door module assembly (DALL-E and Adobe Photoshop)

Scenario E - Assembly of harnesses and cables
Proposed by: Central Manufacturing Engineer

This scenario instructs the operator how to run a cable along the entry threshold of the car, see Figure 16. It involves running the cables through specific holes and attaching them with clips on specific places. This scenario was proposed as either an AR or VR scenario for use when training of the operators with the main focus laying on the sequence itself.

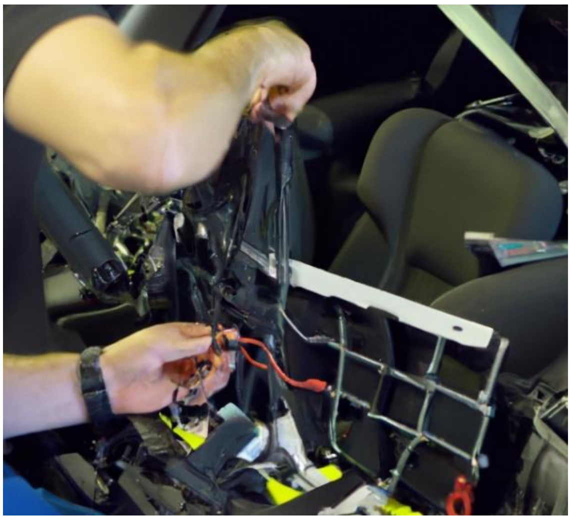

Figure 16: Car harness illustration (DALL-E and Adobe Photoshop)

Scenario F - Assembly of rubber seal in doors
Proposed by: Central Manufacturing Engineer

This scenario is about the installation of a rubber seal strip around the opening of a car door, see Figure 17. This scenario was proposed to utilize either AR or VR to show how to correctly place the rubber seal and where to press the seal to the frame to ensure no leakage.

Figure 17: Rubber seal assembly illustration (DALL-E and Adobe Photoshop)

Scenario G - Assembly of leveling sensor
Proposed by: Simulation Engineer and Manufacturing engineer

In this scenario, a leveling sensor should be connected to the rear axle of a car, see Figure 18. It starts off by inserting the upper hook on the sensor in a hole. The upper screw is then tightened with a tool. The lower part of the sensor is then adjusted so that the lower hook connects to another hole further down. Finally, the lower screw is tightened also with a tool. This scenario is a bit ambiguous in the way that the hole needs to be located, the sensor should be held in one hand and the tool in the other at the same time. The linkages on the sensor being movable add another level of complexity since they need to be adjusted. VR was proposed to be used for this scenario.

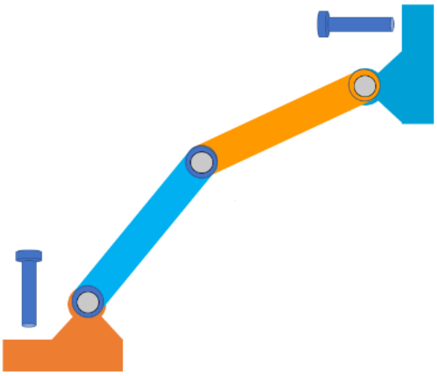

Figure 18: Visual representation of leveling sensor (Own picture)

Scenario H - Place spare wheel in the trunk
Proposed by: Manufacturing engineer

This scenario contains installation of a spare wheel in the trunk of an SUV. Firstly, the cover needs to be removed to open the space in the trunk floor. The wheel then needs to be inserted and covered with the cover again. This case was proposed to use VR or AR to show the correct placement of the wheel to decrease the number of errors.

Scenario I - Control unit assembly
Proposed by: Manufacturing engineer

Assembly of control unit in VR that is first inserted into a casing by sticking it down. Think of it like putting a VHS cassette inside its casing. The casing with the control unit is then pressed in place in the car and the assembly is finished by putting a cover on top.

Scenario J - Wrapping finished car with protective blanket
Proposed by: Added Value Time Spec and Manufacturing engineer

When a car is ready from the factory it needs to be wrapped in a protective wrapping. This is to protect the car from the elements while being transported to the customer or the retailer, see Figure 19. This wrapping is quite complicated to install correctly to ensure tight seal and not forgetting anything. This scenario proposes an XR solution that shows how to connect the wrapping and what to think about during every step. AR might be used while performing the wrapping, where it pops up what to do by the mirror, by the doors etc. This means that the operator gets added information while performing this task. This would decrease the number of mistakes and ensure that all steps are taken correctly.

Figure 19: Wrapping of finished car (Dall-E and Adobe Photoshop)

Scenario K - Securing of cables below car
Proposed by: Manufacturing engineer

This case is about inserting two cables into slots below the car in VR. They are inserted kind of like an ethernet cable and pressed until they are clicked in place. Then a bracket is used to secure the two cables and it ends with the press of a button.

Scenario L - Rear dampers case
Proposed by: Manufacturing engineer

Preparing rear dampers with the help of a press machine before the damper is assembled onto the car chassis. The idea was to both create the spring and the machine in VR and train the operator in what buttons to press, in which order and where to use which tools. Another idea is to use AR to guide the user when training on the actual machine.

4.3 Scenario evaluation

In this chapter the result from the scenario evaluation will be presented. It begins by presenting the requirement specification, followed by the results of the chosen matrices leading up to the chosen scenarios.

4.3.1 Requirement specification

The final requirement specification contains five criteria for the digital instructions, as seen in Table 10 below. The first three are connected to previous studies in the field of XR and virtual manufacturing and are confirmed by the interview with the launch specialist and the main stakeholder is the operator. In an optimal scenario, the demos shall contain many steps, have a high step variety and the original instructions on paper should be ambiguous.

The last two criteria are connected to development time and time restriction of the thesis itself and are derived from the group members' own experience. The first one is XR feasibility, meaning that the scenario should be replicable virtually in a good way. The second one is the estimated development time of the demos due to the limited testing phase.

Table 10: Requirement specification

Requirement specification				
Criteria	Target Value	Verification method	Stakeholder	Source
Shall contain many steps	The steps shall be hard to remember due to the shear number of instructions	Interviews	Operator	Literature
High step variety	The instructions shall be hard due to the number of different steps	Interviews	Operator	Literature
Ambiguous instructions	The instructions shall be hard due to problems with visualizing the instruction	Interviews	Operator	Literature
XR feasibility	The scenario shall be possible to create by two mechanical engineering students	Testing	The group members	The group members
Short XR development time	The scenario shall be posible to create in the time span of this thesis	Testing	The group members	The group members

4.3.2 Pugh matrix

In the first iteration of the Pugh matrix, scenario A was chosen as reference. The results from the matrix were that scenario F and H received the lowest score as seen in Table 11. They received a score of minus one and zero, meaning they were worse than or equal to the reference. The best performing scenarios were G and I which both received a score of three. The most common score was one with six scenarios having that score.

Table 11: First Pugh's matrix

Criteria	A	B	C	D	E	F	G	H	I	J	K	L
Shall contain many steps	ref	+	0	+	+	0	+	0	+	+	0	+
High step variety	ref	-	0	0	+	-	+	-	0	+	0	+
Ambiguous instructions	ref	-	0	-	+	+	+	-	0	+	-	+
XR feasability	ref	+	0	+	-	-	+	+	+	-	+	-
Short XR development time	ref	+	+	+	-	0	-	+	+	-	+	-
Sum +	ref	3	1	3	3	1	4	2	3	3	2	3
Sum -	ref	2	0	1	2	2	1	2	0	2	1	2
Total	ref	1	1	2	1	-1	3	0	3	1	1	1

In the second iteration of the Pugh matrix, seen in Table 12, alternative D was chosen as reference. This was motivated by it receiving a score of two before, placing it high up but not at the top. Once again F and H scored low, but it went even worse for scenario C, receiving a score of minus four. It was first decided to eliminate all scenarios receiving a negative score, but the two scenarios with minus one was kept as a safety margin, in order to ensure the quality of the evaluation. Scenario A, B, C and F were however eliminated.

Table 12: Second Pugh matrix

Criteria	A	B	C	D	E	F	G	H	I	J	K	L
Shall contain many steps	-	-	-	ref	0	-	+	-	0	-	-	+
High step variety	0	-	-	ref	0	-	+	-	0	+	-	+
Ambiguous instructions	+	-	0	ref	+	+	+	-	0	+	0	+
XR feasability	-	0	-	ref	-	-	-	+	0	-	0	-
Short XR development time	-	+	-	ref	-	-	-	+	+	-	+	-
Sum +	1	1	0	ref	1	1	3	2	1	3	1	3
Sum -	3	3	4	ref	2	3	2	3	0	2	2	2
Total	-2	-2	-4	ref	-1	-2	1	-1	1	1	-1	1

4.3.3 Weighing matrix

The result of the weighing matrix showed that the most important criteria was XR feasibility when choosing scenarios. As seen in the rightmost column in Table 13 below, it received a score of 4 and a relative score of 0.4. The least important criteria turned out to be the one where a scenario shall contain many steps. It was less important than any of the others, receiving a score of zero, thus leading to a relative score of zero.

Table 13: Weighing matrix

Criteria	Shall contain many steps	High step variety	Ambiguous instructions	XR feasibility	Short XR development time	∑	∑rel
Shall contain many steps	-	0	0	0	0	0	0
High step variety	1	-	0	0	1	2	0,2
Ambiguous instructions	1	1	-	0	1	3	0,3
XR feasibility	1	1	1	-	1	4	0,4
Short XR development time	1	0	0	0	-	1	0,1
						Tot	**Tot**
						10	1

4.3.4 Kesselring matrix

After having put in the remaining scenarios in the Kesselring matrix and scored them according to weight and fulfillment, the winning ones were scenario G and D. As seen, highlighted in green in Table 14 below, they received a score of 4.2 and 4.0 respectively. Worth noting is that they are two very different scenarios, a screw assembly, and a sensor assembly both scoring high in different criteria. They are highlighted in green and are the ones who will be further developed.

Table 14: Kesselring matrix

		Ideal		D		E		G		H		I		J		K		L	
Criteria	**w**	**v**	**t**	**v**	**t**	**v**	**t**	**v**	**t**	**v**	**t**	**v**	**t**	**v**	**t**	**v**	**t**	**v**	**t**
Shall contain many steps	0	5	0	5	0	3	0	3	0	1	0	3	0	5	0	3	0	5	0
High step variety	0.2	5	1	3	0.6	2	0.4	4	0.8	2	0.4	2	0.4	4	0.8	2	0.4	3	0.6
Ambiguous instructions	0.3	5	1.5	3	0.9	5	1.5	5	1.5	1	0.3	1	0.3	5	1.5	2	0.6	3	0.9
XR feasibility	0.4	5	2	5	2	2	0.8	4	1.6	4	1.6	5	2	1	0.4	5	2	1	0.4
Short XR development time	0.1	5	0.5	5	0.5	2	0.2	3	0.3	5	0.5	4	0.4	1	0.1	3	0.3	1	0.1
Score			5		4		2.9		4.2		2.8		3.1		2.8		3.3		2
Average		5	1	4.2	0.8	2.8	0.58	3.8	0.84	2.2	0.56	3	0.62	3.2	0.56	3	0.66	2.6	0.4
Ranking					2		5		1		6		4		6		3		7

4.4 Development

This chapter presents the results from the development section. It brings up the most important feedback from the experts and how it was used to make as good demos as possible before testing them. The chapter ends with a description of how the two demos turned out.

4.4.1 Expert feedback

The feedback from the experts mostly contained improvements from a user perspective. Things such as highlight colors, arrow alignments, immersion and guiding were in focus. The full transcript can be found in Appendix B and the key points are listed below.

- Consider another option than color due to potential color blindness
- Add more immersion, ambience sound and backgrounds
- Use arrows to point the user in the right direction
- Do not use the highlight color on other objects or CAD-files, this can confuse the user
- Make screw highlights blue instead of red
- Voice instructions can be hard to follow, consider adding text as well
- Add a reset button to restart current step or instruction if the user missed some info
- Add reminders if the user is too slow in performing the current action

From the Gemba walk, it was noticed that the power drill was connected to the roof through an elastic rope. This prevented it from dropping to the floor. The door frames were tilted backward to make it easier to screw the screws at the bottom. The leveling sensor proved to be black in color and was connected with one hand and tightened with the other.

4.4.2 Final demos

The final demos inherited much of the feedback provided by the experts. In the sensor demo, the rear axle and sensor were recolored in more neutral colors. This made the highlights pop more and easier to detect, see Figure 20. Arrows were added in front of the holes where the hook was to be inserted, top and bottom, see Figure 21. Whenever an object, such as the sensor or the tool was to be picked up, it was highlighted in blue instead of red. The highlight for the sensor was made blue and when it was in correct position, it turned green, also seen in Figure 21. Sound was added to the tool, imitating the real tool.

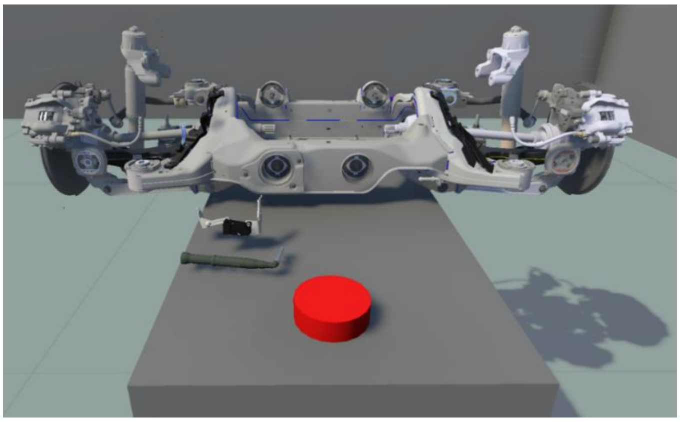

Figure 20: Final sensor demo

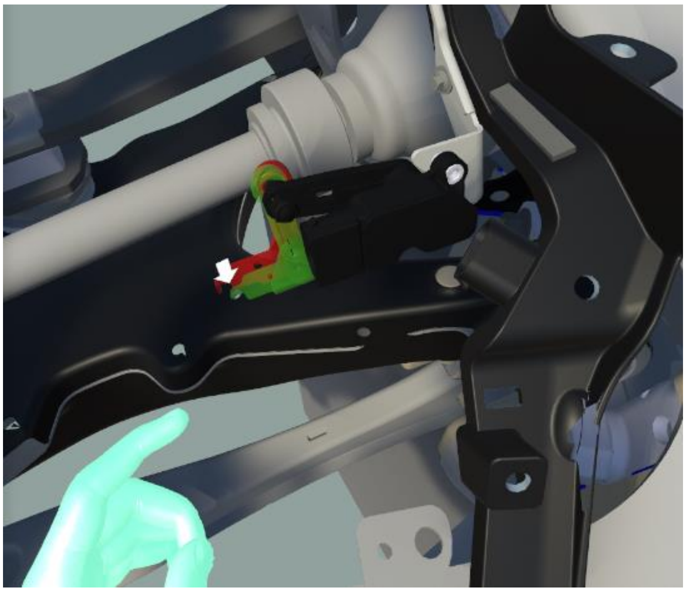

Figure 21: Arrow showing where the lower hook should be inserted

In the door module demo, the door module highlight was changed to blue and when picked up, a text box appeared, telling the user to turn around, see Figure 22. When reaching for the power drill, now hanging with an elastic rope, an arrow was added pointing toward it, see Figure 23. Some immersion was added such as more doors waiting in line in different colors and walls and floor were recolored to make it look more like a plant. The door frame was also tilted to resemble the real-life scenario. Like the sensor demo, the power drill got a sound effect. The pictures from the door assembly are partially blurred due to company secrecy.

Figure 22: Text guiding the user to turn around

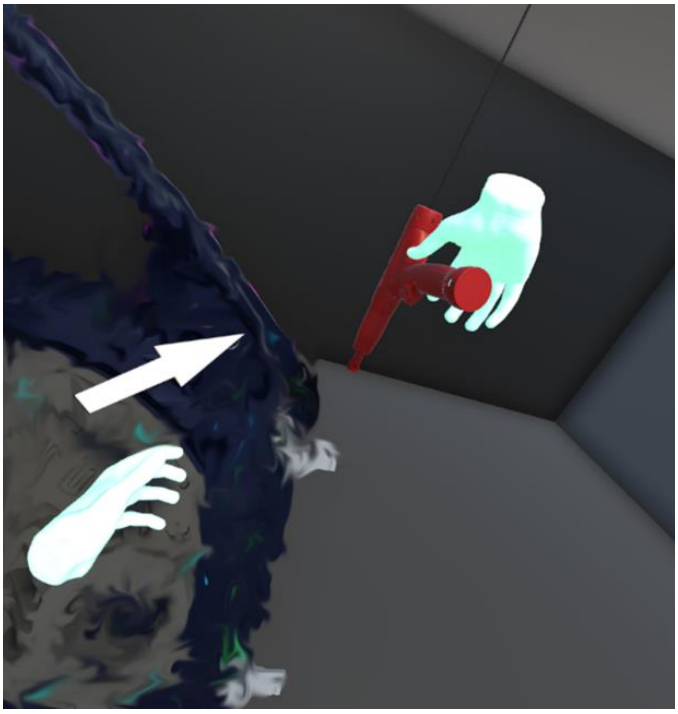

Figure 23: Arrow pointing toward the power drill hanging in the air

4.5 Testing results

After having sorted the qualitative data and sorted it into categories, two tables were created, one for each category. The following sub-chapters present the main principles learned regarding the two categories together with which stakeholder requested them and how these principles support future work with XR-supported training instructions.

4.5.1 Category 1: Aim of XR instructions

The first category, Aim of XR instructions, was split into 7 sub-categories as seen in Table 15 below. The first two categories bring up important principles to think about before starting development. The other five categories should be considered when developing the instructions as well as when planning and preparing for implementation.

Table 15: Principles regarding Aim of XR instructions

Category	Principles	Stakeholder	Description of benefits
Purpose	• Important to specify the purpose of the instruction • Operations not connected to the purpose should be easy to complete.	• Launch specialist • Digitalization expert	When developing instructions, the purpose need to be stated from the get-go. Every instruction cannot test every aspect at the same time. Purposes not considered in the instruction should be easy to complete to not disturb the workflow, e.g., assembly operations in an ergonomics instruction.
Complexity	• Make sure the chosen instructions are complex enough • Should be long and contain varying steps • Consider using for cable harnesses and clips • Consider scenarios with high risk, like battery scenarios with high voltage	• Launch specialist • Simulation engineer • Manufacturing engineer • Digitalization expert	Complex scenarios utilizes VR in more ways. In order to be efficient when developing instructions, save the VR instructions for when they are most needed. This includes complex scenarios or scenarios where there might be danger of harming the operator.
Ergonomics	• Instructions should consider ergonomics • Tools should be held correct, in correct hand • Posture checks should be implemented • Should not be possible to screw from wrong angles • Some way of informing weight of objects • Make height adjustable	• Launch specialist • Simulation engineer • Shop floor engineer • Manufacturing engineer • VR expert	Make the demos usable for ergonomics simulations, making instructions more valuable. This includes warnings when standing the wrong way or holding a tool in an unergonomic angle. The floor should be adjusted to either fit the standard length used within the company or be adjustable for tall or short people. Consider AR with real life props where weight is important.
Graphics	• Make stations look like the real ones if the goal is to learn a full sequence • Make realistic floor in scenarios where you move around much • Use realistic sounds and backgrounds • Find a good balance between immersion and development time	• Launch specialist • Shop floor engineer • Digitalization expert • Simulation engineer	Making realistic environments make the instruction feel more real. In long sequences with much movement, such instructions can help prepare the operator better. A balance between realism and development time is needed for rapid development.
Repeatability	• Keep in mind that instructions might need a couple of tries before it sticks. • Digital instructions should be placed close to the real build	• Launch specialists • Simulation engineer • Manufacturing engineer	For the operator to repeat the steps in real life, they need to be given time to train in VR first. By having the training close to the real build, it will be possible to walk back and forth.
Savings	• Digital instructions limit the need for expensive training cars • Limits the use of paper instructions	• Launch specialist	By using digital instructions, less material is wasted on test cars. By getting rid of paper instructions, additional savings are made. Company might become more sustainable and more cost effective.
Future of tech	• Combining VR instructions with virtual build cars in the future • Such technology need to be supported on many levels within the company • Great for showing and learning, not as good for judging performance	• Launch specialist • Simulation engineer • Digitalization expert • Manufacturing engineer	Before implementing VR, it is important to have in mind all levels within the company. By combining VR with real prototypes, it adds another layer of realism before stepping out on the assembly line.

4.5.2 *Category 2: User Interaction*

The second category, User Interaction, was broken down into 11 sub-categories. In Table 16 below, all principles are listed. The first seven principles show what to keep in mind when developing the instructions and the last four are more connected to hardware, location, and the testing itself, ending with some technical difficulties that might arise.

Table 16: Principles regarding User Interaction

Category	Principles	Stakeholder	Description of benefits
Complex bodies	• Dynamic parts like joints are hard to implement • Direction of the joint should be obvious • Soft bodies like cables are hard to implement and ruin immersion	• Launch specialist • Shop floor engineer • Digitalization expert • Simulation engineer	If objects need to be dynamic or soft, they need to be implemented well to not disturb workflow. Making direction obvious removes any doubt regarding where to twist and turn objects.
Voice instructions	• Voice instructions should be combined with text • Voice should not be too fast • Add repeat button to repeat the current step	• Launch specialist • Shop floor engineer • Digitalization expert • Simulation engineer	By combining voice and text, workflow is easier. The tempo of the voice should be quite slow to be more comprehensible. The repeat button makes it possible to still complete the instructions even though information is missed.
Feedback	• Feedback when a tool is placed correctly, such as highlighting the screw or controller vibrations • Add feedback in the controllers when screwing is done	• Launch specialist • Shop floor engineer • Digitalization expert	This type of feedback improves workflow and removes possible doubts for the user when performing tasks.
Highlights	• Use colors with high contrast to highlight objects • The highlights should pulsate for easy detection	• Launch specialist • Shop floor engineer • Simulation engineer	By highlighting tools and screws the operator can easier detect what to do next. The highlights should be of high contrast for easy detection. By making the highlights pulsate they are easier to detect from a distance.
Extra indicators	• Use dynamic arrows for guidance with high contrast • Make it clear if assembly order does or does not matter • Make direction of objects obvious • Show a live demonstration or video before training	• Launch specialist • Shop floor engineer • Digitalization expert • Simulation engineer	Increases the detectability of arrows and eases workflow. By pointing out if order matters, the operators does not have to figure it out on their own. By making directions obvious, no time need to be spent on thinking about if parts are upside down or not. A recording makes it easier to replicate the first time.
Predictability	• Stick to the same rules for every interaction • Snap zones and tools should be predictable • Highlights, arrows, voice and text instructions should always function the same way	• Launch specialist • Digitalization expert	By setting up rules for how the game logic works, it is easier to predict how the steps should be carried out. A screwdriver should always work the same way, just like snap-zones should always have the same tolerances. This reduces the risk of distractions in the workflow.
View	• Make it possible to see through models • Consider making a full virtual body • Make the environments well lit • Consider zoom capabilities where it is hard to see	• Launch specialist • Simulation engineer	By seeing through models, it is allowed to train assembling of hidden parts. Add zoom capabilities to easier see. By using full body models, it is easier to understand how you stand. Can help with ergonomics simulations.
Controller	• Use intuitive controllers • Give clear controller instructions • Turn off locomotion, rotation and teleportation for unexperienced users	• Launch specialist • Shop floor engineer • Simulation engineer • Manufacturing engineer	By using intuitive controllers together with a description before hand, there will be less distractions related to how to navigate through the instructions. By turning off the walk, rotate and teleport, there is no risk of unwanted locomotion or teleportation the first time. Consider use only for experienced VR-users.
Boundaries	• Have a dedicated room for the instructions • Make sure sensors are high up and not covered • Consider toggling see-through mode on the headset	• Launch specialist • Shop floor • Simulation engineer	By having a dedicated room mapped according to the instructions, the risk of walking outside the boundaries are eliminated. Sensors should not be covered by furniture to eliminate sync errors. A see through mode in the HMD can make orientation easier.
Training before demo	• Create training environment that teach the operator all the tools and common operations	• Launch specialist • Shop floor engineer • Digitalization expert	A VR playroom with all tools, possible assembly scenarios and an introduction to arrows, highlights and other feedback makes the user more ready before the real training. This makes it possible to up the difficulty and realism of the instructions.
Technical problems	• Spend time on testing demos for bugs and glitches • Turn off collisions between the avatar and the environment • Turn off gravity when not needed • Snap zones should not be too tight • Objects should not get stuck inside each other	• Launch specialist • Shop floor engineer • Digitalization expert • Simulation engineer • Manufacturing engineer • VR expert	Instructions without glitches improve workflow. Turning off collision of avatar eliminates the risk of teleporting up in the air or accidentally throwing objects away. By turning off gravity on objects, there is no need to restart when items fall through the floor. If two objects with collisions are placed inside each other, they might get stuck. Try to avoid this happening to increase workflow.

5 Discussion

This chapter begins by discussing the results in accordance with the two research questions. Methods used to reach the results are discussed to address both validity of the results as well as to bring up hindrances and how they were mitigated. This is followed up with a discussion of what implications that can be made from this study, where it is positioned in the research field and how it can contribute on a larger scale. Potential roads ahead for future research in the field of digital training of operators are presented at the end of the chapter.

5.1 Useful scenarios for XR instructions

The first research question aimed at finding during which scenarios XR instructions proved to be useful. The general conclusion was that complex assembly operations with many steps benefit the most from an XR solution. The instructions should be hard to visualize in your head when reading them off a paper and contain high step variation. This was in line with what was found in previous studies (Gong, 2020). Another commonly requested use case for digital instructions was when training in dangerous environments, such as batteries with high voltage. Such scenarios could either hurt the user directly, or if not assembled correctly, could result in hurting someone else afterward. By giving virtual training, it would be possible to practice without danger until becoming confident, hopefully increasing the safety in the industries. This goes in line with studies arguing for VR to increase both awareness, preparedness as well as safety behavior (Talabă & Angelos, 2008) as presented in the theoretical framework. The same was said for training operators ordered to work in factories not yet built or where major changes are being carried out. An XR solution allows for training beforehand, making them ready to work from day one but also to evaluate a station to see if it works as intended. If changes need to be made, they are discovered early and therefore cheaper to address.

Scenarios requiring many virtual build cars was pointed out by several as being perfect for XR solutions as they require a lot of physical material. This material is usually scrapped and by reducing the use of real parts when training, less material is wasted. This is both beneficial for the environment and can potentially save money.

5.2 Principles learned by testing XR instructions

From developing and testing scenarios on real practitioners, important principles could be learned, thus answering the second research question. By following these principles in the future development of XR instructions, the instructions should hopefully be of higher quality. Less time can also be spent on development since there now exists more guidelines about what the operators want and what is currently possible with the technology.

It was discovered that VR instructions seem promising as a training tool for both new operators, and operators learning a new station. Everyone agreed that they would be able to repeat the same steps in real life either directly or after practicing a couple of times more in VR.

Regarding the immersion and level of detail of the demos, most agreed that it was enough. Some people would have liked ambient sounds and surroundings resembling a factory. The common statement from the launch specialists, however, was that it was enough. Details such as extra doors waiting in line added some sense of realism but made them confused as to which door to go to and which module to pick up. It was also pointed out by most that you could tighten screws from unrealistic angles and in unergonomic poses. The tool could also be held in ways that would quickly wear your wrists. The possibility to build more doors on a row and measure the time with a stopwatch.

Most of the above can be boiled down to the aim of the specific instruction. These demos aimed to only teach the sequence, nothing else. From the launch specialists, it was proposed to specify that aim and make different difficulty levels for the demos, starting off with only the sequence. After learning the sequence, it should then be possible to level up and learn ergonomics for the same assembly with the final level having a stopwatch, measuring the assembly time.

User interactions need to be considered as well when designing instructions in XR. From the testing, it was realized that having colors in high contrast was something the launch specialists wanted. The highlights and arrows should also flash or pulsate to make them more detectable. This contradicts what the experts from RISE and University of Skövde said, who wanted highlights to be blue due to red being associated with errors. The voice instructions were hard for some to notice, and it was advised to combine them with floating text as well as adding the possibility of repeating them. The HTC Vive controllers were perceived unintuitive for some, making it hard to understand how to grip, interact and walk around. Controllers with joysticks, such as the Oculus Quest controllers would probably have made the walking and turning easier to comprehend for first time users. However, the younger testers with experience with VR or video games in general showed no difficulties at all. This shows a need for experience in VR itself before performing the instructions. Something like PlayStation’s VR playroom should therefore be implemented but for Volvo Cars. Here all different tools, controls and tasks could be taught to the operator at his or her own pace before starting the real instructions. This makes the operator more experienced and shortens development time for each instruction since it can be assumed that everyone knows how everything works.

5.3 Methodological reflection

The research methods used were all taken from courses taught in the product development master’s program at Chalmers. One central part in product development is being able to identify customer needs, come up with potential solutions and tailor them to fit the customer's needs. Using selection matrices to funnel down project is commonly referred to as the product development funnel and was in this case applied on the 12 identified cases. Usually, you have large quantities of ideas and requirements, meaning that the ones eliminated most often were bad to begin with. In a project like this, with only 12 ideas, the quality of the down selection process is reduced. Scenarios who were believed to be perfect for VR or AR were eliminated simply due to them performing worse than the winners, not because they were bad. Two cases in particular were the wrapping of a finished car and cable management. They scored high in complexity, number of steps and step variation. The limiting factor was instead XR feasibility and development time, both being a consequence of this being a thesis and the technology not being there yet. The final scenarios were instead pointed out as being too simple. In particular, the door module did not need an XR instruction, while the leveling sensor was perceived as a bit more complicated. This, however, did not affect the results since high complexity and step variety was pointed out as important anyways.

The affinity mapping, also known as the KJ-method, is commonly used to sort qualitative data such as the one gotten from the testing. There are, however, steps taken that might have affected the results. During the testing, it was hard to get hold of people one by one. Instead, most of the tests were carried out in a group with more of a group discussion at the end. This might potentially have led to skewed results in the affinity diagram. To begin with, participants might have affected each other's ideas and thoughts. Secondly, participants who tested last had the opportunity to see their colleagues perform before them. This made it easier for them to replicate and not miss crucial information that the ones before them did.

The group testing also impacted the quantity of answers in several ways. Firstly, each input had to be counted as a single answer, even if participants might have had the same ideas if interviewed individually. Additionally, the relatively small test sample, consisting of only 18 individuals, could have influenced the outcomes, especially considering that half of them were not main stakeholders but rather included to increase the quantity. To mitigate this, one solution was to multiply the input by the number of attendees in that test session. However, assuming that they would all provide the same responses could potentially lead to manipulated results. Instead, the feedback was weighed differently when setting up the principles lists where the green notes were held in higher regard than the others. This was important when feedback differed, such as the highlight color or immersion level. By stating which stakeholder requested what in the list, it is possible to decide for oneself if that principle is worth following or not. It is also possible to dive into the transcripts and affinity diagrams manually and only look for the needs of whichever stakeholder.

By visiting the factory numerous times to both see how operations are made and how the chosen scenarios are done, the quality of the demos is ensured. It was further improved by the feedback from experts in the field of virtual manufacturing to ensure as polished demos as possible. By getting feedback from actual practitioners with experience of both operator training and assembly, the identified scenarios and the test results have a close connection to the industry.

5.4 Challenges to account for

A recurring theme throughout this thesis is challenges related to hardware that hopefully can be avoided in the future. Working with software like Unity or Unreal requires substantial computing power. The initially planned XR-room at Volvo Cars was no longer available. Therefore, initial work started in the VR lab at Chalmers FUSE, where two sets of HTC Vive and gaming computers were accessible. However, this imposed limitations, as the lab was shared with other students, allowing only three days a week for our work. When real CAD files from Volvo Cars were employed, the rest of the work had to be carried out at a spare computer in the HoloLens room. This meant even less time to work each week. Therefore, it is recommended to have an empty room ready from the get-go somewhere at Volvo Cars.

It is also recommended to leave even more headroom for delays in the testing than anticipated in this project. Even though a lot of headroom was planned for, the tests ran three weeks too late. Finding operators and booking time for tests proved harder than we thought, and it was also requested a testing room closer to the plant. In this case, a second computer was used close to the plant, something that was not expected from the beginning.

Unexpected occurrences such as computer malfunctions also need to be accounted for. The computer in the HoloLens room malfunctioned during testing and tests at PVH was resorted to yet another computer. The new computer had an older HTC Vive, leading to compatibilities that had to be addressed. Fortunately, only one week was consumed in our case, but having two setups with the same hardware decreases the risk of something like this happening.

In an optimal scenario where it is possible to work unhindered on two separate computers, each with their own headset, the developed demos should turn out much better. This would allow working on one demo 8 hours per day straight. The other benefit would be the possibility to create more demos with more variation, allowing for more test moments. It would also remove the hassle of changing the play area between the different rooms, allowing the instructions to be tailored to the specific room as well as allowing tests in AR. Time was also spent on learning C# and setting up demos from scratch. By utilizing a plugin such as VR-builder or similar together with Volvo CAD-files from the get-go, development and learning time could probably be cut in half.

5.5 Implications of Research

As described in the introduction chapter, the research field is limited when it comes to applying XR instructions on real life cases. Studies, such as (Asklund & Eriksson, 2018), mention that the technology is there, but it must be tested on industrial practitioners. This thesis has continued that path, using operators and manufacturing engineers from within the manufacturing industry. This is something relatively unexplored, making this thesis novel in many ways. One of the scenarios is for a planned car while the other is currently in operation. By doing this, it was possible for the practitioners to compare the XR instructions with the current situation. This placed the input and XR benefits in a perspective closer to reality. The potential use of XR instructions for the future has therefore been verified and overall perceived as positive. Other research has mentioned uncertainties regarding how instructions should be created to ensure user satisfaction (Helldén & Karlsson, 2020). This study has collected such feedback from industrial practitioners and the most important principles have been identified together with what benefit those would bring.

It can also be implied that instructions like these can improve the quality of the training due to them being more standardized. Nothing goes missing from the paper instruction to reality, since virtual training both tells and shows how everything should be done. Virtual training also limits the use of physical training material, something that might lead to decreased environmental impact connected to training. In a future with more virtual training, it might lead to more sustainable industries, both environmentally and economically.

5.6 Future work

This project serves as a foundational step towards future research in the realm of XR implementation for operator training. However, there remains a substantial amount of unexplored territory that must be traversed to effectively deploy such instructional methods on a large scale. Consequently, further investigations are warranted in the field of XR to bridge the existing gaps in knowledge. For instance, it became evident that prior experience in virtual reality significantly influenced a user's performance within the environment. It would be intriguing to examine which types of instructions are most suitable based on an individual's experience level. Notably, during the testing phase, one participant with limited VR experience failed to perceive the presence of voice instructions and instead relied solely on the visual highlighting cues. Given the diverse range of individuals with varying backgrounds employed in contemporary industrial settings, it becomes crucial to explore the influence of experience levels on VR training outcomes. Mastery of VR is a skill that necessitates training to achieve proficiency, akin to video games offering different difficulty levels tailored to one's skill level, thereby providing appropriate assistance based on the chosen setting.

In future research, it would be worthwhile to explore the applicability of a tool like VR builder for the creation of instructions in AR. This exploration could hold the potential to reduce development time for AR instructions significantly. Additionally, conducting a comparative study between VR and AR could provide valuable insights. By testing both scenarios side by side, it would be possible to assess the advantages and disadvantages of utilizing each technology within an industrial setting. Such an investigation would contribute to a comprehensive understanding of the benefits and limitations associated with VR and AR, informing decision-makers regarding their optimal implementation.

6 Conclusions

Throughout this master's thesis, the possibility of implementing XR as a tool for training operators has been explored. The main aim was to find during which scenarios these types of instructions seemed to be most useful and to find principles to have in mind when developing instructions in the future.

The work began by studying the field of virtual manufacturing to find out what software and hardware exists, where the research currently is in the field and current applications of XR in the industry today. Important stakeholders were identified and talked to in order to ensure the delivered instructions meet their demands and expectations. Through classic product development, scenarios were identified and funneled down in accordance with the stakeholder needs and developed in Unity and tested with HTC Vive. The instructions were tested on experts within manufacturing, some of which with many years of experience as operators.

In conclusion, the instructions that benefit the most from an XR solution are the ones with high complexity and many and varied steps. They should be either hard to interpret when on paper, or easy to forget. Other potential use cases are for dangerous operations such as for batteries with high voltage or to limit the use of virtual build cars to save money and reduce material waste.

When developing XR instructions, it is important to have a well-defined purpose for every individual instruction. This can vary from only teaching a sequence to teaching ergonomics and performing tasks within a short time frame. This allows for a much easier workflow and dedication both during development and during training. User interactions such as the controls, VR experience, guidance, highlights need to be considered to ensure high accessibility of the instructions.

While studies have shown that XR can be a useful tool for informing and training operators, this study applies that principle to real cases from the industry. They have been tested by experienced experts and the feedback has been turned into a set of principles. These principles could potentially be used in future development of XR instructions to speed up development time and ensure instructions of higher quality.

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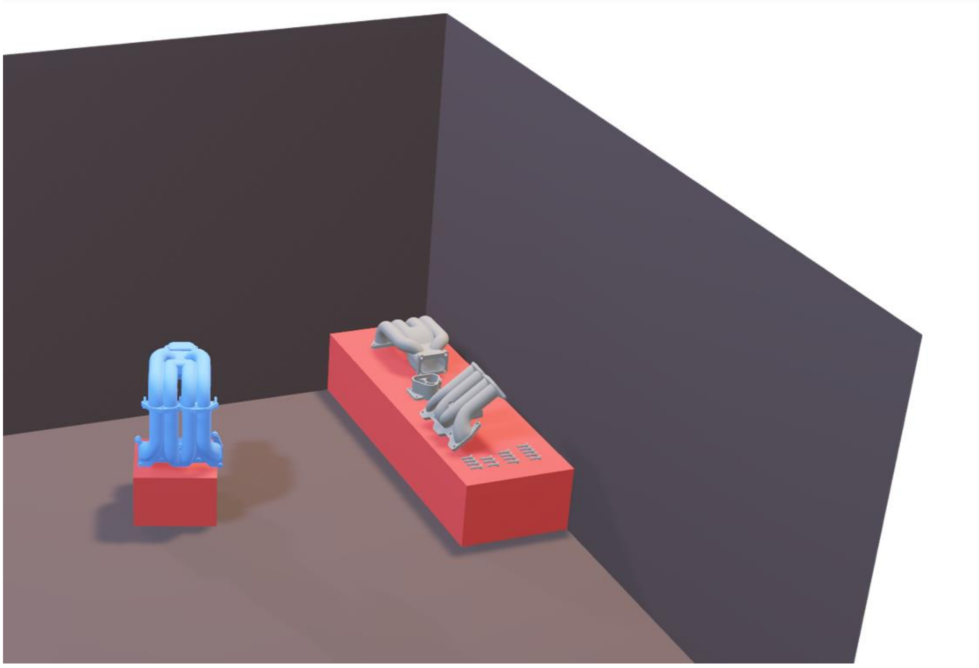
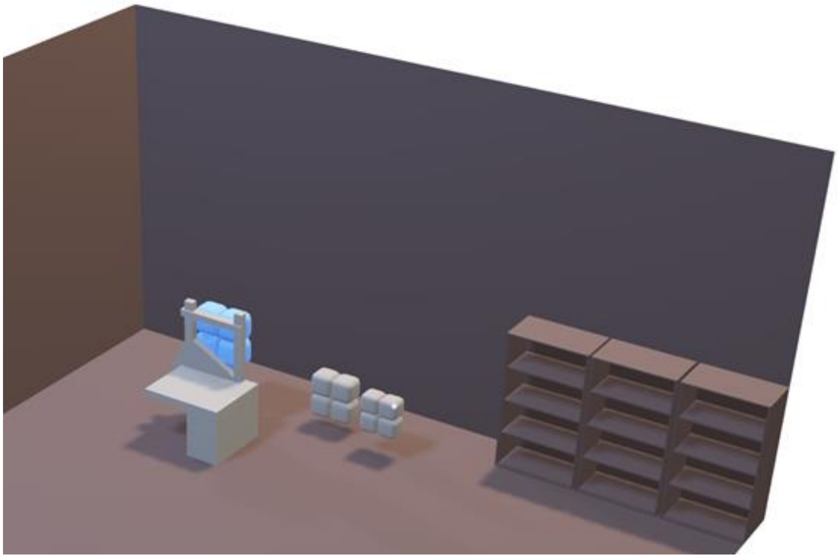
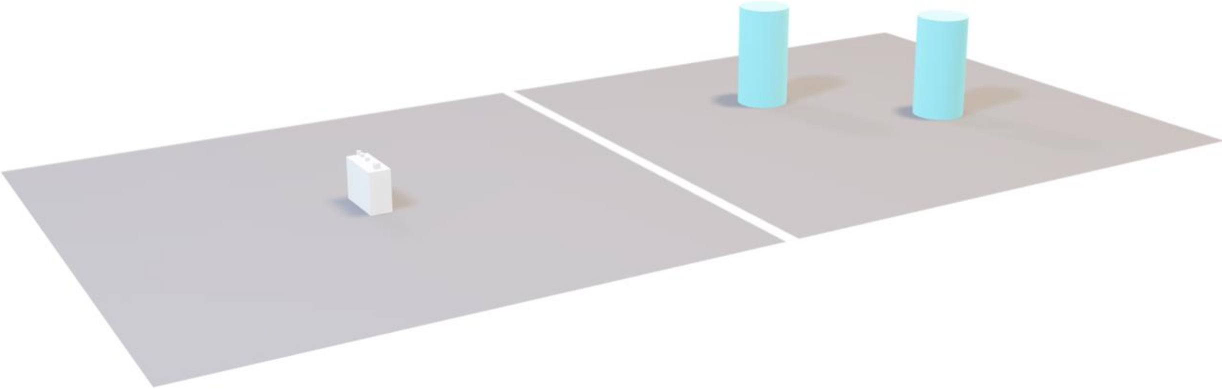
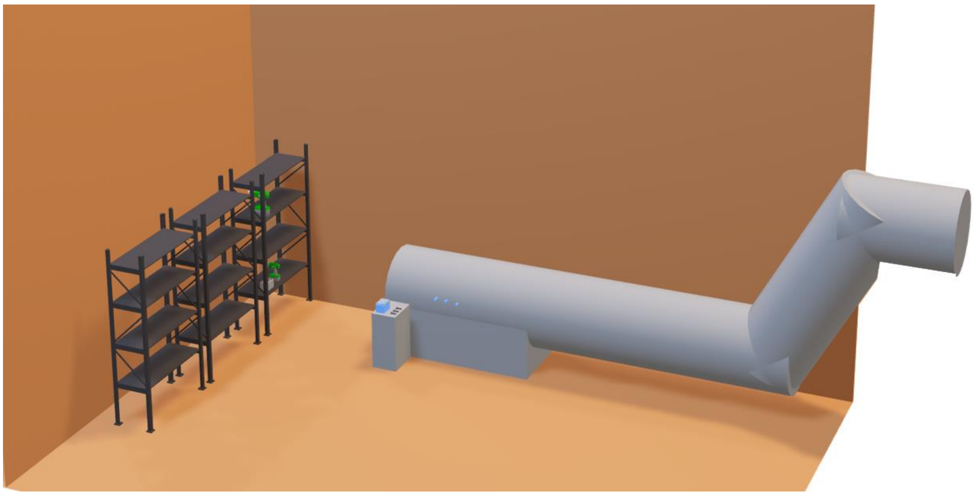
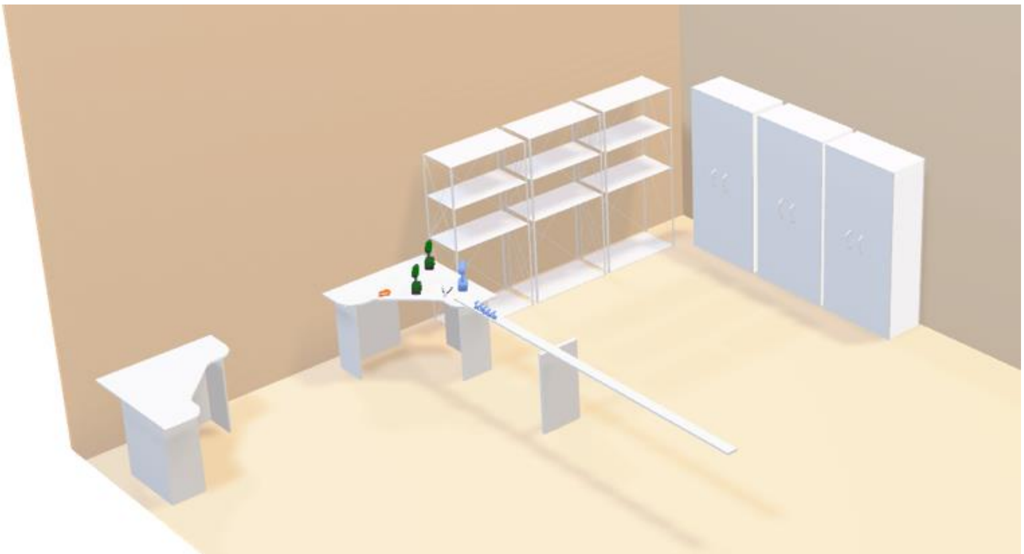
Appendix A - Learning environments











Appendix B - Expert Transcript

Interview with: Method developer

What is your background or position?

Metodutvecklare med eget intresse för VR

Sitter på ME Body

Do you think that the demos lacked any critical information that is important for the operator?

På sensorn visa vilken sida som är upp och vilken som skall montera?

Kanske göra att sensorn får olika färger för upp och ner så man vet vad som skall monteras var?

Gör hitboxen mindre för sensorn

Även här force feedback

Regarding UX/UI, do you have any tips on the use of highlighting or user guidance to use in the demos? For example, we have highlighted things in red, is there a better way?

Lägg in force feedback eller vibrationer I kontrollen i stället för borrljud?

Talet som instruktion är lätt att missa, kanske behövs en reset-knapp. Vid längre instruktioner I tal kan det vara komplicerat för alla kan inte koncentrera sig på att lyssna för länge?

Kanske ha en ljudfeedback på skruven när den är i ändläget?

Do you think that the demos could be simplified?

Gärna komplettera ljuden med en pil som pekar eller något vid exempel plocka upp skruvdragaren så det blir övertydligt.

Do you think that the information was presented at the right time?

Japp, men kanske överväga det där med reset-knappen ifall man missar något

Do you think that the demos had enough level of detail?

Det skulle jag säga

Interview with Strategy digital manager

What is your background or position?

Strategy digital manager

Do you think that the demos lacked any critical information that is important for the operator?

Lite mer information om de prylarna man ska montera I en sådan här vy. Kanske hade varit bra att se vad artikeln heter, vilket artikelnummer och på sikt vilken bilmodell det är som kommer. I nästa steg kanske det kommer en annan variant. Så bygga på med ett mer realistiskt flöde. Om man tränar en operatör kommer det komma från olika modeller så då meddela att "här kommer modell X och nu kommer modell Y".

Innan man trycker på knappen kanske det kan säga "doorline station 4, denna bil och så vidare"

Regarding UX/UI, do you have any tips on the use of highlighting or user guidance to use in the demos? For example, we have highlighted things in red, is there a better way?

I Siemens program *process simulate 2206* som är liknande visas highlights på ungefär samma sätt för var man ska snappa objekt på plats. Dock är highlightsen gröna och inte röda.

Do you think that the demos could be simplified?

Tyckte det som var med behövdes

Do you think that the information was presented at the right time?

Ja det tyckte jag

Do you think that the demos had enough level of detail?

Mer realistisk omgivning, göra det mer realistiskt. Kanske greppa panelen med två händer. Ha kanske i textform framför en eller i sidan, vad det är man skall göra här näst.

I sensorn kolliderar skruvdragaren i sensorn, man hade kunnat fixa kollisionen där.

Kanske se till att man ser hela mänskliga kroppen för att öka inlevelsen i stället för bara händerna?

Interview with RISE and University of Skövde

What is your background or position?

Researchers within virtual manufacturing at RISE

Professor in user interaction at Högskolan i Skövde

Do you think that the demos lacked any critical information that is important for the operator?

Consider adding more arrows at the correct places to ensure user understanding.

Regarding UX/UI, do you have any tips on the use of highlighting or user guidance to use in the demos? For example, we have highlighted things in red, is there a better way?

Do not use red! Use blue instead!

The color might be problematic for color blind people if we only use red/green so maybe use other colors or add arrows. Let's say if we look away first, we might not notice that an object has changed color to red.

Do you think that the demos could be simplified?

Rather make them more detailed with ambience, backgrounds, and stuff to increase realism.

Do you think that the information was presented at the right time?

Need a process that controls that the operator follows the instruction, like following it to see that he looks at the right way. Red might be problematic since it is used to signal that something is alarming.

People might not be familiar with VR, what happens if they do something that is wrong? Will you tell them that they are doing it wrong?

Do you think that the demos had enough level of detail?

Check immersion level, tactical inversion where you are immersed in the situation, something we might use due to research pointing to it. Sensory immersion, you feel the same thing we would feel in real life? Maybe adding a soundscape, ambience, or something? Maybe we have not even been hired by Volvo yet? This is how it feels to be in a factory? We should keep some level of immersion to make it feel real. Using a full body avatar, something discussed in the larger research project, like using mannequins for simulation ergonomics to enhance the sense of embodiment. Maybe look for some asset?

Interview with UX Professor

What is your background or position?

Professor inom interaktionsdesign på Chalmers

Do you think that the demos lacked any critical information that is important for the operator?

Viktigt att veta var man skall kolla, hela idén med VR är att ha med saker som inte går I verkligheten så som pilar och flytande text.

Regarding UX/UI, do you have any tips on the use of highlighting or user guidance to use in the demos? For example, we have highlighted things in red, is there a better way?

Pilarna återigen

Do you think that the demos could be simplified?

Nej snarare att det behövs läggas till fler saker som bakgrunder, immersion i form av ljud och annat för att styrka illusionen av en verklig fabrik.

Do you think that the information was presented at the right time?

Ja det tyckte jag

Do you think that the demos had enough level of detail?

Kanske se till att man vid alla lägen vet var man ska kolla så lägg in saker som att man ska vända sig. Kanske möjlighet att starta om steg. Även möjligheten att läsa om instruktionen om det gått för lång tid att utföra senaste steget som en form av påminnelse.

Appendix C – Test Questions

Interview questions

Intro questions:

1. **What's your role in production?**

2. **Have you ever experienced VR before?**

Result:

3. **Did you encounter any problems with following the instructions?**

   Yes:

   Can you describe a time when you were given instructions that were not straightforward and how you navigated through the situation?

   No:

   Even though you didn't encounter any problems, can you see a situation in this demo where someone less might misunderstand the instructions.

4. **Do you think that you could replicate the step taken in VR in real life?**

   Yes:

   Are there any steps in the instruction that you think might be more challenging than others?

   No:

   Why don't you think that you will be able to replicate the actions taken and what more information is required for you to complete the action in real life.

5. **Did you have any technical problems performing the demo such as potential input lag or bugs in the demo?**

Information:

6. **Do you think that the demos lacked some critical information that's important for the operator?**

   Yes:

   What problem could you see occurring if this information is lacking?

   No:

   Do you have any suggestions on potential information that might be interesting to have in the demos?

7. **Do you think that the demos hade too much information?**

   Yes:

   Do you think that any of the information was redundant and should be taken away from the demos? Could you give some examples?

No:

Do you think that the demos could have more information and if so, could you give an example?

8. **Do you think that the information was presented at the right time?**

Yes:

Do you think that there were some instances when it was better or worse and if so, could you give some examples?

No:

Can you give some examples of

Suitable tool:

9. **Do you think that VR was a suitable learning tool for these scenarios and if not, would you prefer something else? If so, why?**

10. **Do you think that the scenarios themselves were complex enough and therefore had a need for clarifying instructions?**

11. **Do you think that this type of instruction looks promising for the future of the automotive industry?**

Yes:

Why do you think so?

No:

Why do you think so?

12. **Do you think that the level of detail in the demos was well suited to this type of instruction?**

Yes:

Do you think that the detail level could be lower and still perform as well as now?

No:

Can you give an example when the detail level of the demo effected the result of the demos

Appendix D – Test transcripts

Interview with 5 Launch specialists

Intro questions:

1. **What's your role in production?**

Launch specialister och planners

Alla fem har erfarenhet som montörer innan, kombinerat över 100 års erfarenhet

Har också projektkunskap I tidig fas, kunskap inom ergonomi och risk

En har jobbat med dörrar, fast då var det i dörrverkstad (S80)

2. **Have you ever used VR before?**

Inte alls

Inte alls, bara lite playstation

Helt nytt

Inte alls

Inte alls

Result:

3. **Were you able to perform the task by following the VR instructions?**

Dina händer och fotrörelser registrerades inte för hur man stod, kanske ha något för fötterna kopplat till det?

Knapparna är svåra, särskilt grepp-funktionen

Finns bättre kontroller, just greppfunktionen var jobbig

Gör i stället så att dragaren fastnar i handen

Gör inte så saker faller till backen

4. **Do you think that you could repeat the same steps in real life as in VR?**

På dörren, utan tvekan men att lära sig en hel balans är nog inte så enkelt

Ja då, man förstod ju sekvenserna efter att ha gjort dem i VR, men kanske hade behövt se någon annan göra eller göra om det själv ett antal gånger till först.

5. **Did you have any technical problems performing the demo such as potential input lag or bugs in the demo?**

Gick in I väggen ett antal gånger

Kom åt gå-funktionen eller rotera-funktionen av misstag. Stäng av den och ha ett större rum.

Om man tappade skruvdragaren innan första skruven skruvades I började steget om och man fick höra rösten läsas upp igen.

Svårt att lära sig spela med helt nytt sätt att tänka. Svårt när man inte såg sina armar och ben.

Om man släppte sladden på fel ställe fastnade den och det gick inte att greppa den igen, detta ledde till att demot fick startas om

Om man kom åt dörrmodulen på fel vis flög man upp I luften

Kom åt teleportfunktionen några gånger och teleporterades iväg långt bort

Information:

6. **Do you think that the demos lacked any critical information that is important for the operator?**

Gör pilarna I en avvikande färg, inte VIT, utan gör gult. Starka färger typ orange?
Zoomning när man skulle hitta undre länkarmsfästet, var svårt att gå nära och se? Man kanske bör böja sig ner och kika in närmare?
Om vi gör en provvisning, zooma in på kroken/piggen och visa hur den skall sitta! Är det något som är dolt eller halvdolt så visa det. Dolda vinklar liksom.

7. **Do you think that the demos could be simplified?**

Snarare lägga till mer tydliga saker. Kanske hade varit bra att fått träna I VR först innan man hoppade in I världen?

8. **Do you think that the information was presented at the right time?**

Om man hade fått se det först hade det blivit lättare? Nu kom rösten lite direkt och det var knappt så man var förberedd på det. Men av att ha sett andra göra demot innan visste man vad man skulle göra. Rösten kom lite jobbigt. Var för snabb så rösten sa vad jag skulle göra efter att det redan var gjort?

Suitable tool:

9. **Do you think that VR was a suitable learning tool for these scenarios? Compare it to the current situation?**

Doorline är ju en av de enklare och bättre. Är inte värt att göra dörren. Hade jag valt att göra en simulering hade det varit värt att göra det på något som tar mer tid. Kanske en A-stolpes-panel hade varit bra? EN sekvens där det är många steg och varierande som just A-stolpe med massa clips och kablar.
VR skulle vara väldigt vettigt till slangar, kontaktorer, clips osv.
Kanske lättare att bara se sekvensen, filmen är ju görbart? Alla sekvenser måste man kanske inte testa själv utan räcker med att se någon annan göra det eller att man spelar in.

10. **Do you think the scenarios are complicated enough to motivate the use of VR?**

Som sagt är ju dörren den lättaste av de alla och kanske inte hade behövt en demo I VR men allt beror på syfte. Är det för ergonomi kan VR ändå vara bra här, men instruktionerna I sig är inte så svåra att de nyttjar VR. Demo två var ju mer värd att ha som demo, inte svår men mer avancerad att förstå. Särskilt det med att sätta i en krok och böja sig in i bakaxeln.

11. **Do you think that this type of instruction would be used widely in your factory/work?**

Redan för 10 år sedan snackade de ju om detta och det har ju bara blivit bättre och bättre. Har hört att mercedes eller något som har liknande. Finns ju företag som har hela fabrikerna på detta vis?
Fråga efter önskemål innan, önskemål på saker där VR kan nyttjas? De har fått pärmar som är hur tjocka som helst som hade varit så mycket bättre om det varit digitalt. Bättre att få det visuellt? Man glömmer också 90% av allt man får lära sig ur pärmen?

Känns som framtiden, särskilt för dyra saker man vill investera mycket i och testa. Har också hög coolhetsfaktor. Får ni jobb inom detta på Volvo så blir ni rika, finns jättemycket man kan utvinna på detta! Både ekonomiskt och i miljöhänsyn, slippa bygga alla teststationer.
Mycket kastas när man lär sig bygga bilar, med detta slipper saker slängas! Både bilar och annan utrustning som bara slösas bort och kastas. Här kan man spara både tid och pengar!
Har man en nyanställd är det jättebra som inlärning? Här är maskinen den funkar så här. Behöver ju inte vara fokus på montering bara? Så här byter du en hylsa, så här backar du en maskin, allt beror ju på syfte. Ska det va monteringssekvenser eller är det för ergonomi? Skulle man kolla ergonomin hade jag velat ha en operatör från banan som vet hur scenarierna går till. Här får man bara ut position.

12. **Do you think that the demos had enough level of detail?**

Ja det här var bra, inga ljud och annat. Dörrarna i bakgrunden gjorde att man fattade att det var en line, men behöver inte vara så mycket mer. Bra ändå att det är lite väggar runt om så man faktiskt ser att det är en dörr där. Hade velat se armar och ben eller hela kroppen så man såg om man krockade med armen i ett objekt eller inte.

Man känner dock inte vikten, man känner ju inte trögheten. Man lär sig bara var detaljer ska sitta?
Du behöver få en feedback eller kvittens när kontaktdonet är kopplat
Kvittens på att du klickat, att hylsan är på
Syn, hörsel, känsel måste ha feedback
Möjlighet att kunna gå in och se i modellen vore bra?
Sladden var konstig, svår att förstå vad man gjorde med den
Hade varit gött att komma in i miljön, ha ett spel där det går att pilla och placera i miljön lite som ett spel eller en assembly i VR.
Lägg lite tid på att göra så GOLVET ser ut ordentligt för det är det man ofta orienterar sig efter. Golvets markeringar används ofta till det (tidigare operatör). Värt vid en större station där man rör sig en del.

Interview with 3 Launch specialists

Intro questions:

1. **What's your role in production?**

Vårt jobb är att utbilda! Alla har jobbat som operatörer.
Launch specialist, quality A-fabrik
Launch specialist, quality A-fabrik
Launch specialist

2. **Have you ever used VR before?**

Ja, testat titta på en fabrik I VR
Ja, ergonomibedömningar
En gång, eller var det två?

Result:

3. **Were you able to perform the task by following the VR instructions?**

Yes, it was no problems
No problems
Had to make one restart, otherwise it was no problem

4. **Do you think that you could repeat the same steps in real life as in VR?**

Tycker det var skitbra i utbildningssyfte
Ja det hade jag kunnat gjort
Man förstår hur man ska göra, på vilket sätt?
Först ge en sån här demo och sedan under övervakning hoppa på banan istället för att köra study car direkt.
Finns en balans där man också måste ha tagit på grejerna fysiskt först, men detta är bra.

5. **Did you have any technical problems performing the demo such as potential input lag or bugs in the demo?**

Flög upp i luften först
Andra demot kändes mer säkert att hoppa in i
I demo ett när jag flyttade kabeln hackade det till i bild lite.
Allt ba försvann vid dörren när jag stod nära väggen, sensorn kan ha varit täckt.

Information:

6. **Do you think that the demos lacked any critical information that is important for the operator?**

Att skruven var blå i sensor-demot för den var färglagd i röd?
Hade velat se connection med skruvdragaren när den var på skruven? Vibration eller färgändring.

Göra något kritiskt, typ koppla på en batteripol. Säkerhetsrutor som säger vad det faktiskt är man skall göra.

Nu får man online träning och läser på papper när man lär sig batteri och airbag. Här I VR tror jag det sätter sig bättre I huvudet. Så förtydliga kritiska moment I VR så man lär sig och varför.

Ergo i stil med att när man kanske ska klättra in i en bil, så man inte slår i huvudet. Om man byter från en XC-bil till en sedan kanske man är van med en högre höjd.

Vid ergonomi, göra så att man får höra att man gör fel, så man tränar kroppen samtidigt.

7. **Do you think that the demos could be simplified?**

Var ganska spot on faktiskt
Spot on, fungerade bra

8. **Do you think that the information was presented at the right time?**

När jag gjorde första modulen var jag lite sen, var tvungen att vänta på att rösten skulle säga klart det jag skulle göra. Men det är för att jag hade fått se innan hur jag skulle göra.
Jag lärde mig genom att se det först på TV-skärmen. Det är också roligt och lärorikt. Att se en inspelning av demot innan man hoppar in hade hjälpt, jag tittade på när kollegan gjorde demot första gången så när jag körde kunde jag göra samma.
En repetitions-funktion för rösten de gånger man tappar bort sig.

Suitable tool:

9. **Do you think that VR was a suitable learning tool for these scenarios? Compare it to the current situation?**

Absolut! Vi använder detta massor inom vårt jobb, både med ergo men nu också med utvärderingar. Man kan mycket tidigare i fas upptäcka ett problem.
Detta är framtiden, kommer bara bli mer och mer av sådant här
Man får inte känslan riktigt I VR. Man upplever det på ett helt okej sätt men man kanske hade velat känna på sakerna också. Man kanske får höra att något är tungt I VR, men man känner det inte. Så vad gäller kroppshållning här så känner man inte det (Liselott och hennes snack om att behöva använda lyftaren till dörren)
För sådan typ av ergo är det nog bättre med AR där man kan ha den fysiska saker I rummet så man kan klämma och känna av vikten.

10. **Do you think the scenarios are complicated enough to motivate the use of VR?**

I informationssyfte fungerar det bra, det var såpass komplext att man fattar.
Hade dock velat kunan testa dolda monteringar. Här hade det varit bättre kanske om man hade fått klämma och känna (spontant tänker jag AR där).
Ska man prova på i grupp är det rätt lagom demon. Men är man själv och tränar skulle man gärna kunna stå och bygga en hel bana i VR om möjligt. Få med montering där man behöver flytta sig i balansen, gå tillbaka flera gånger och hämta materialet och så vidare. (likt det folk sa på TC-15)

11. **Do you think that this type of instruction would be used widely in your factory/work?**

Ja, just nu har ju A-fabriken hela fabriken så man kan vara inne I 3D-miljön och testa och ändra på saker utan att det blir så dyrt. I och med att man har allt inscannat kan man då ta färdiga miljöer och pilla i innan det byggs färdigt. Spar pengar och resurser.

12. **Do you think that the demos had enough level of detail?**

Tror det kommer ta mer tid att skapa massa detaljer än vad man får ut från det. Det hade I så fall varit om man hade haft en färdig bakgrund så det inte tar så lång tid. Om man hade velat göra en hel balans där det är relevant.

Om man faktiskt skall gå fram och tillbaka och hämta saker och ting kan det vara av värde. Annars känner det inte så nödvändigt.

Interview with 4 Shop floor engineers

Intro questions:

1. **What's your role in production?**

All 4 shop floor engineers

2. **Have you ever used VR before?**

Second time
Second time
Second time
I use it sometimes in my work, so I know all the basics

Result:

3. **Were you able to perform the task by following the VR instructions?**

Yes, it was possible without too much of a hassle.
Yes, I reached the end of both demos
I finished both but walked outside the room a couple of times

4. **Do you think that you could repeat the same steps in real life as in VR?**

Yes, I think I would be able to replicate after some more tests.
Yes, probably since the demos was not too hard and I now know all the basics

5. **Did you have any technical problems performing the demo such as potential input lag or bugs in the demo?**

Yes, the tool was dropped inside of the table and disappeared
It glitched a bit with the boundaries
Walked outside the room many times
Accidentally came into contact with the walking/rotation
Teleported by mistake a couple of times
The bottom part of the sensor was hard to align and bugged out, started to spin
Accidentally rotated and teleported

Information:

6. **Do you think that the demos lacked any critical information that is important for the operator?**

Would have liked more arrows that pointed us toward the goal
The voice was enough

7. **Do you think that the demos could be simplified?**

Rather the opposite, more arrows and guiding
Maybe more obvious how the sensor should be moved sideways
I think it had enough information

8. **Do you think that the information was presented at the right time?**

The voice commands were nice and easy to follow
The highlights in blue were nice

Suitable tool:

9. **Do you think that VR was a suitable learning tool for these scenarios? Compare it to the current situation?**

I think this is going to be even better and better in the future. Train here many times and then go up and do It in real life.

Better dexterity since hands is not hands with the cnotrollers. With better ahnd tracking stuff you can better get the feeling on how to do. Hololens with hand tracking is nice since then you have your fingers.
Maybe it's good to have some kind of startup level to learn the buttons and such. We were new so we had some problems getting the hang of the basics. This allows the user to put full focus on just doing the demos.

10. **Do you think the scenarios are complicated enough to motivate the use of VR?**

Since there are many small steps which is nice. We do not think that videos would be better than video Also in terms of ergonomics you can get the feeling of leaning in under and test how you reach stuff or not and your stance when doing it.
How is it with moving stations? I think the doorline moves right? You should also move to VR as well. Chase after the doors and the axis.

11. **Do you think that this type of instruction would be used widely in your factory/work?**

Yes, absolutely in the future. Train first and when the factory is done or when they should start to work, they are more confident.
As long as they put much research and resources into developing these types of demos.
With VR you might get enough confidence. Good way of training before walking out on the real station.

12. **Do you think that the demos had enough level of detail?**

I would really like to have some more level of detail, more the feeling of a factory.
Maybe some factory sounds to give me the feeling of being in the factory?
Maybe adding a foreman screaming at me so I start working more efficiently.
You should fix it so that you can add things with both hands simultaneously. Also, in the demo with the sensor it was possible to screw using the right hand. This is not ergonomic in the long run, so if ergonomics were a factor, tell the user to use the left hand instead.

Interview with Digitalization expert

Intro questions:

1. **What's your role in production?**

Digitalisation expert

2. **Have you ever used VR before?**

Ja, och även forskat och handlett exjobb inom VR och testat många olika demos

Result:

3. **Were you able to perform the task by following the VR instructions?**

Vid bildörr-panelen var hitboxen så stor att när jag skulle montera den tänkte jag släppa den I luften för att rotera den, men så snappade den på plats. Det var jag inte beredd på. Detta gjorde att jag förväntade mig samma typ av snapzone I sensor-demot. Att korrigera undre delen av sensorn var svårt.

4. **Do you think that you could repeat the same steps in real life as in VR?**

Inte på bara en gång, hade nog fått upprepas några gånger. Om det är längre sekvenser hade jag behövt längre tid.

5. **Did you have any technical problems performing the demo such as potential input lag or bugs in the demo?**

Nej jag trodde att jag skulle vara van vid andra kontroller, men efter två sekunder gick det bra. Det var vissa grejer jag hade förväntat mig skulle ske annorlunda, alltså att miljön skulle fungera på andra sätt. Pilen jag inte såg på sensor hade jag förväntat mig att den hade blinkat eller något.

Information:

6. **Do you think that the demos lacked any critical information that is important for the operator?**

Vissa saker var inte självklara, men ni får också ta in det att ska det vara med viss symmetri? Ska man kunna montera saker genom väggar? Ska det kunna stoppas in från 180 grader? Allt är en fråga om vad man förväntar sig när man kör demot? Svårt att bygga miljön utifrån vad användaren förväntar sig. Om man hade kunnat tänka ytterligare ett steg, kanske hjälp med pilar, någon form av guidening och I första demot när man tog upp panelen var det svårt eller otydligt var man skulle sätta dit den. Här var man tvungen att skruva I en viss sekvens, se till att det förekommer tydligt. För sen kanske man kommer till en sekvens där sekvensen faktiskt spelar roll och där är det viktigt att veta det.

Kanske ha att man placerar tillbaka verktygen igen.

I verkligheten känner man motstånd när en skruv är skruvad till max, detta går inte att märka med kontroller om man kanske inte har en form av vibration.

Man får va viktig med vad syftet är för om syftet här är att lära sig sekvensen och det finns saker man hakar upp sig på som stör flowet så stoppar det upp inlärningen av sekvensen.

7. **Do you think that the demos could be simplified?**

Personligen känner jag att man kanske skulle haft med mer information? Mer text och så vidare. Om man ska göra detta stroskaligt hade det behövts en tutorial där man lär sig VR och alla verktygen först och sedan är det bara att hoppa in I världen och plöja demon. Just nu blev det att man fick lära sig hur VR fungerade medan man utförde demos.

8. **Do you think that the information was presented at the right time?**

Tyckte det var bra tajming. Ljudfeedbacken kom lagom i tid.

Suitable tool:

9. **Do you think that VR was a suitable learning tool for these scenarios? Compare it to the current situation?**

Jag tror det hade varit mer värt om det hade varit längre sekvenser.

10. **Do you think the scenarios are complicated enough to motivate the use of VR?**

Just dessa demon är aningen korta för att motivera VR. Hade varit okej om det hade varit säkerhet inkopplat I demona eller något för att styrka eller motivera att använda VR.

11. **Do you think that this type of instruction would be used widely in your factory/work?**

Finns definitivt potential, bästa vore om det blir standardiserat nog att kunna snabbt bygga ihop ett demo med hög kvalitet. Så det inte tar för lång tid att bygga dem, då hade det varit en het kandidat.

12. **Do you think that the demos had enough level of detail?**

Ja det tyckte jag. Syftet är ju att lära sig en sekvens och då behövs det ingen mer information. Andra moment kanske snarare blir mer störande. Om det däremot blir större sekvenser och man går runt mycket kan det vara bra om det återspeglar verkligheten. Säg att man lär sig att ett verktyg sitter vid en viss pelare eller något ligger under en viss lampa, då är det värt att ha hög fidelity.

Detaljer som produkten, verktygen och så vidare måste ha hög detaljnivå. Saker I bakgrunden är inte lika viktiga.

Interview with ME and 2 Simulation engineers

Intro questions:

1. **What's your role in production?**

Manufacturing engineer

2x simulation engineers

2. **Have you ever used VR before?**

Jobbar med att sätta upp ergonomisimuleringar i AR och VR

Jadå

Result:

3. **Were you able to perform the task by following the VR instructions?**

Jadå

Absolut

Ja

4. **Do you think that you could repeat the same steps in real life as in VR?**

Jadå

Ja men hur nära inpå ska man bygga en fysisk sådan här? Det påverkar ju hur bra man måste va i VR först.

5. **Did you have any technical problems performing the demo such as potential input lag or bugs in the demo?**

Skruven i dörrmodulen

Information:

6. **Do you think that the demos lacked any critical information that is important for the operator?**

Inte som jag tänkte på

Positionen på kroppen, hur man stod, fel höjd

Levelingsensorn såg kanske inte ut som man höll den?

7. **Do you think that the demos could be simplified?**

Det enda var verktyget, I det andra fallet skulle ju verktyget sitta på ett visst sätt. Här kan man borra med fel hand.

Det där andra grepp-sättet är nog inte bättre

Tweaka greppet så det blir rätt istället, ha två olika lägen så när man kommer till den andra skruven så ska man ändra ställningen det där med koordinaterna I rymden.

8. **Do you think that the information was presented at the right time?**

Ja det tyckte jag

I case två var det lite fler saker centrerade, gör så färgen hade pulserat så man lättare såg

Suitable tool:

9. **Do you think that VR was a suitable learning tool for these scenarios? Compare it to the current situation?**

Ja absolut

Ja för lära I VR, men inte att bedöma I VR.
Om det bara är lärosyfte som så här ska du stå?

10. **Do you think the scenarios are complicated enough to motivate the use of VR?**

Som ett första steg? Man lär sig greppa och så.
Nja, man kanske inte behöver se dörren i VR, det är mer komplexa instruktioner och FARLIGA instruktioner med ström.
Instruktioner med olika sekvensordning
Kabelmattan och vehicle cover hade motiverat mycket mer

11. **Do you think that this type of instruction would be used widely in your factory/work?**

Ja det tror vi
Jadå det tror vi
Då tycker jag det skall finnas ett rum i fabriken där man tas in och får testa
I svåra saker ofta har man en handledare och då kan det gå bra, men i sekvenser där det är farligt eller komplext så är det bra att kunna testa själv här I VR
Det är nog ett roligare sätt att lära sig på
När folk är nya kan detta va en bra lösning att öva på
Detta är ett sätta att kvalitetssäkra, idag när man lär sig muntligt kan det vara så att man bedömer fel och lär ut fel vilket riskerar kvaliteten.

12. **Do you think that the demos had enough level of detail?**

Vi vill gärna få in så mycket realism som mycket men om man bara skall lära sig är detta tillräckligt.

Kan va viktigt om man har något som ligger framför mig att det också är med I VR så jag känner igen mig sen när jag kommer till fabriken
Är viktigt att man slår i saker så man krockar i dem

Interview with 1 simulation engineer and 1 VR expert

Intro questions:

1. **What's your role in production?**

Simulation engineer

Method developer simulation and offline programming (VR expert)

2. **Have you ever used VR before?**

Eeeeeh of course

Yes

Result:

3. **Were you able to perform the task by following the VR instructions?**

Yes

No, I followed the instructions, but the first thing blew away

4. **Do you think that you could repeat the same steps in real life as in VR?**

I suppose so yeah

Yes, if I got some trials

Pretty straight forwards in terms of instructions so yes

5. **Did you have any technical problems performing the demo such as potential input lag or bugs in the demo?**

The cable got stuck

It was possible to just lob the door module into the frame

A few of them yes

When holding the tool

Using the tool with the side buttons were weird since this is not usually the way you do it here

Information:

6. **Do you think that the demos lacked any critical information that is important for the operator?**

The first thing about grabbing, tell the user which button to use when grabbing. A short instruction where the buttons are pointed out

7. **Do you think that the demos could be simplified?**

Quite straight forward as it is already

No, I agree

8. **Do you think that the information was presented at the right time?**

If you are new to the system, the voice instructions were very fast. It was hard to keep up when I was teleporting around. Too fast in the beginning. Both text and voice would have been pretty good

Since I had already seen the recordings before, it went okay

Suitable tool:

9. **Do you think that VR was a suitable learning tool for these scenarios? Compare it to the current situation?**

Yes, it could be combined with more complex scenarios like longer ones.
You get visualization, you get models, perception, surrounding on paper you don't get the feelings
What could be added on, on the door having something thinking about ergonomics!

10. **Do you think the scenarios are complicated enough to motivate the use of VR?**

I would not say there were complicated, they should have been longer
Too many bugs for people to be able to use it, the screwing tool was a bit wacked. A bit audio lag with the screwing and the animations
If you show this to a kid born today in like 2005, they must be better and smoother with less bugs

11. **Do you think that this type of instruction would be used widely in your factory/work?**

No idea
It could be used for training
If you look at the robot simulations used to introduce people, then yes

12. **Do you think that the demos had enough level of detail?**

The shadows are a bit dark
It was good, enough

Appendix E – Aim of XR Instructions

Appendix F – User Interaction

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Gothenburg, Sweden 2023
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