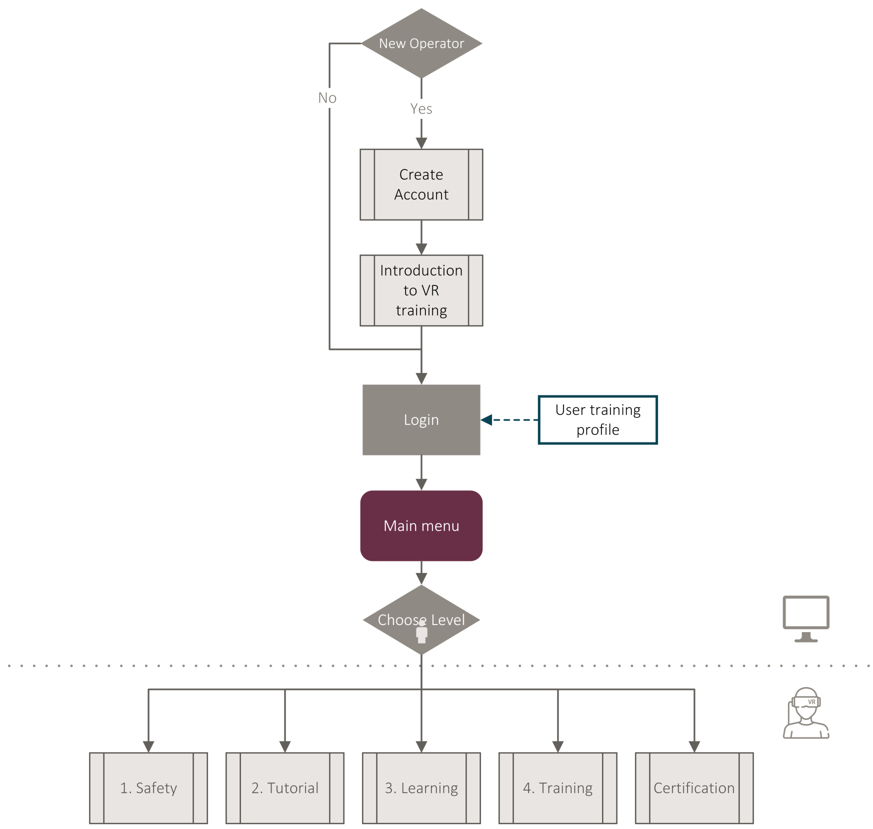
CHALMERS
UNIVERSITY OF TECHNOLOGY



Workflow for Training in Virtual Reality

Introducing Virtual Reality in Training of Operators for Manual Assembly

Master's thesis in Production Engineering

HENRIK BERNHARTZ
LISA MALIS

Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2019

Master's thesis 2019

Workflow for Training in Virtual Reality

Introducing Virtual Reality in Training of Operators
for Manual Assembly

HENRIK BERNHARTZ
LISA MALIS

Department of Industrial and Material Science
Division of Production Systems
Chalmers University of Technology
Gothenburg, Sweden 2019

Workflow for Training in Virtual Reality
Introducing Virtual Reality in Training of Operators for Manual Assembly
HENRIK BERNHARTZ
LISA MALIS

Supervisor: Pierre Johansson, Volvo GTO
Supervisor: Arpita Chari, Chalmers, Department of Industrial and Material Science
Examiner: Roland Örtengren, Chalmers, Department of Industrial and Materials Science

Master's Thesis 2019
Department of Industrial and Material Science
Division of Production Systems
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: The main workflow developed for virtual training

Typeset in LaTeX
Printed by Chalmers Reproservice
Gothenburg, Sweden 2019

Workflow for Training in Virtual Reality
Introducing Virtual Reality in Training of Operators for Manual Assembly
HENRIK BERNHARTZ
LISA MALIS
Department of Industrial and Materials Science
Chalmers University of Technology

Abstract

Manufacturing industries that are moving towards a low volume and high variety production will face numerous challenges in the future. The operators are the most flexible part of the production system and their expertise needs to be up to date at any time. To prepare new operators for increasing complexity, efficient training programs are essential. To meet this demand, virtual reality training is introduced in the training process. This thesis investigates the current research on virtual reality learning systems and combines it with the demands from production. A literature study was conducted along with interviews to develop a new workflow for training with virtual reality. The results reveal that virtual training cannot fully replace the current training but can act as a support to ease the cognitive load.

Keywords: Production, Virtual Training, Virtual Reality, Operator, Workflow, Learning, Training.

Acknowledgements

We would like to thank everyone that has contributed to this thesis, especially our industrial supervisor Pierre Johansson for his guidance and support throughout the thesis. We would like to give lots of appreciation to Lennart Malmsköld, at University West, who helped us to set the path for this thesis by sharing his research. Further, we would like to thank our examiner Roland Örtengren and our supervisor Arpita Chari for their support and expertise in the research area of this thesis. Finally, we would like to thank researchers and production employees within Volvo Group Trucks Operations for their involvement in our thesis.

Henrik Bernhartz & Lisa Malis, Gothenburg, June, 2019

Word list

AR	Augmented Reality
GTO	Group Trucks Operations
HMD	Head Mounted Display
JI	Job Instruction
SOP	Standard Operation Procedure
SPRINT	Integrated Production System
TWI	Training Within Industries
VR	Virtual Reality

Contents

List of Figures **xv**

List of Tables **xvii**

1 Introduction **1**

1.1 Background 1

1.2 Purpose and research questions 2

1.3 Case company Volvo Group Trucks Operations 2

1.4 Delimitations 3

1.5 Outline of the thesis 3

2 Theoretical framework **5**

2.1 Virtual training 5

2.2 Virtual reality 5

2.2.1 Functional description 6

2.2.2 Application areas 6

2.3 Knowledge characteristics 7

2.3.1 Tacit knowledge and articulated knowledge 7

2.3.2 Knowledge transfer and sharing 7

2.4 Learning process 8

2.4.1 Cognitive learning 8

2.4.1.1 Constructivism 8

2.4.2 Contextual learning 8

2.4.3 Learning curve 9

2.4.4 Learning modes 10

2.4.5 Forgetting Curve 10

2.5 Further aspects of learning 11

2.5.1 Behaviour and knowledge levels 11

2.5.2 Motivation 12

2.5.3 Gamification 12

2.6 Training within Industry 13

2.6.1 Job Instruction 4-Step Method 13

3 Methods **15**

3.1 Research approach 15

3.2 Theoretical foundation 16

3.3 Research design 17

3.4 Data collection methods 17
3.4.1 Literature study 17
3.4.2 Interviews 19
3.4.3 Observation 21
3.4.4 Documents 21
3.4.5 Audio and visual materials 21
3.5 Data analysis and validation 21
3.5.1 Grounded theory 21
3.5.2 Triangulation 22
3.5.3 Data saturation 22

4 Current research and production **25**
4.1 Literature study 25
4.1.1 What are the benefits of using VR? 25
4.1.2 What are the drawbacks of using VR? 26
4.1.3 How is it possible to involve learning aspects in VR-training? . 27
4.1.4 What aspects are important to consider when designing virtual training with VR? 28
4.2 Case at Volvo GTO 29
4.2.1 Product 29
4.2.2 Production flow 31
4.3 Current training of operators within Volvo GTO Tuve 32
4.3.1 Introductory training 33
4.3.2 Training process for new operators 33

5 Workflow for virtual training **35**
5.1 Structure of the workflow 35
5.2 General interfaces 36
5.2.1 Main menu 36
5.2.2 Progress bar 38
5.2.3 Help bar 38
5.2.4 Present results 39
5.3 Main flow 40
5.3.1 Training Levels 42
5.3.1.1 Safety level 43
5.3.1.2 Tutorial level 44
5.3.1.3 Learning level 46
5.3.1.4 Training level 48
5.3.1.5 Certification 49

6 Discussion **51**
6.1 Current research and production 51
6.2 Explanation of the workflow 53
6.3 Prerequisites for a successful implementation 60
6.4 Virtual training opportunities 63
6.5 Quality of research 64
6.6 Limitations 64

7 Conclusion **65**
7.1 Future work 66

Bibliography **67**

List of Figures

2.1 HTC vive with controllers 6
2.2 Learning curve. Adopted from [15] 9
2.3 The forgetting curve. From [22] 11
2.4 The job instruction 4-step method 13

3.1 Systematic approach for empirical research. From [29]. 15
3.2 Qualitative research process inspired by [32] 16
3.3 Literature study visualised process 18

4.1 Location of bogie cross member on the chassis, from [52] 29
4.2 Fully equipped bogie cross member, positioned upside down 30
4.3 The production flow of the bogie cross member subassembly 31
4.4 Bogie cross member on the trolley used in subassembly 32

5.1 Proposal for the design of the main menu 37
5.2 Visualisation of the selection of training level 38
5.3 Design of the progress bar 38
5.4 Design of the help bar 39
5.5 Present results from training session 39
5.6 Main flow 41
5.7 Safety flow 43
5.8 Tutorial flow 45
5.9 Learning flow 47
5.10 Training flow 48

6.1 Illustration of the connection between the learning modes, learning curve and the training levels 55

7.1 The main function identified during the three phases 66

List of Tables

3.1 List of interviewees and their expertise 20

5.1 Explanation of symbols used in the workflow 36

6.1 List of requirements to consider when implementing a VR training system 60

1

Introduction

This chapter gives an introduction to the thesis starting with a background to the area of research. The purpose is subsequently presented together with research questions aimed to be answered in the thesis. A short introduction to the case company is introduced. The chapter is finalised by an explanation of the outline of the thesis including where the research questions are aimed to be answered.

1.1 Background

To remain competitive on today's market, manufacturing companies need to be able to assemble numerous kinds of products at the same time on the assembly line [1]. Mixed-model assemblies refer to the concept of creating one core product, but during the assembly, applying variation to the model. This consecutively means that a customer can receive its own personalised product. However, mixed-model assembly generates more complex and varying tasks for the operators. Automated assembly would be much faster and more precise than manual assembly but is not as flexible into changes in the production process. Since the life cycle of a product generation in the automotive industry is rather low, manual assembly is beneficial [2]. Most industries today are acting on a low volume-high variety strategy which increases the need for well trained operators. Operators are exposed to a higher cognitive load than before and their expertise requires to be up to date at any time. The establishment and use of efficient training programs are crucial to face this problem. Physical replicas of the production line are often an expensive investment. Instead, virtual replicas are in many cases implemented.

A lot of research has been made in the area of desktop virtual training. Extensive research made by Malmsköld [3] revealed that computer-based training outperforms traditional training regarding quality aspects and learning. However, it was concluded that it can not yet replace traditional training completely. The next possible step in the development is to base the training programs on virtual reality (VR). With the help of VR, operators can be trained at any time since no real setting is needed. This means that the costs of experimental installations for training and production downtime can be avoided. The industrial relevance of a training system considers two aspects: investment and training [4]. A lot of the design and implementations of VR supported learning are based on the technical aspects. However, they are often lacking well-defined learning theories or custom designed models serving as foundation or guidelines. The research of today is clearly missing a learning model that considers pedagogy [5].

1.2 Purpose and research questions

The purpose of this thesis is to develop a conceptual workflow for operator training using VR. The thesis aim to combine the findings from current research on virtual training with learning theory and the requirements of an industrial setting. The thesis is conducted at Volvo Group Trucks Operations (GTO) and should be used as a guide for further implementation of virtual training. To fulfil the purpose of the thesis, the following research questions will be answered:

RQ.1 *Can virtual training meet the existing learning outcomes in the production environment?*

RQ.2 *What are the main functions to include in a workflow for virtual training?*

To help build a foundation of the current state and to answer the main research questions, the following subquestions will be answered:

SQ.1 *What are the benefits of using VR?*

SQ.2 *What are the drawbacks of using VR?*

SQ.3 *How is it possible to involve learning aspects in VR-training?*

SQ.4 *What aspects are important to consider when designing virtual training with VR?*

1.3 Case company Volvo Group Trucks Operations

The company studied in this thesis is GTO, the truck industrial entity within the Volvo Group responsible for truck manufacturing. GTO is the second largest heavy-duty truck brand in the world with trucks serviced and sold in more than 140 countries. GTO offers a range of medium and heavy-duty trucks as wells as aftermarket products, services and specific offers. The company has a production structure based on global presence, with approximately 95 % of the production capacity located in Sweden, Belgium, Brazil and the USA.

1.4 Delimitations

It is important to stress out that no implementations of the workflow has been planed in this thesis. The results are on a conceptual level and are based on theory and information obtained from production. Ideas and suggestions are presented regarding functions necessary and how they could be implemented, however no real implementation and demonstration with the virtual environment will be made.

This thesis has focused on a single case which means that only a small part of the production has been considered.

The technology used in virtual reality is rapidly and constantly developing. A possible implementation of the workflow in this thesis lies far ahead in time. Therefore, the results presented in this thesis are not dependent on any specific kind of technology. The technology mentioned in the thesis is used only as an example.

1.5 Outline of the thesis

The report is divided into 7 chapters. After the introduction, chapter 2 begins containing a theoretical framework for the thesis. This chapter includes background information about virtual training, VR och several aspects of knowledge and learning. Chapter 3 presents the methods used in the thesis work to obtain the results. The results are divided into two chapters. Chapter 4 presents the findings from the literature study and the current state aiming to answer RQ.1 and subquestions SQ.1-SQ.4. Chapter 5 presents the developed workflow, consecutively answering RQ.2. Next, discussions about the current state and the developed workflow are found in chapter 6. The concept of the workflow is motivated and discussed on a deeper level. Finally, conclusions are drawn in the last chapter 7 together with suggestions of future work within the research area of the thesis.

2

Theoretical framework

This chapter presents a theoretical framework starting with explanations of virtual training and VR. Knowledge and learning aspects and theories are later introduced which will be used in the development of the workflow.

2.1 Virtual training

Virtual training refers to training performed in a virtual or simulated environment and a lot of research has been made within the area [3]. Virtual training can also refer to when the learner and the instructor are in separate locations. Virtual training environments are aimed to be designed to simulate the traditional classroom or learning experience. It allows a more intuitive learning environment than traditional classroom-based training [6]. Virtual training in the context of this thesis is defined as training that is undertaken within a virtual environment using virtual reality technologies.

2.2 Virtual reality

VR is the application of computer technology to create a simulated environment. Compared to traditional interfaces, VR places the user inside an experience and the user is able to interact in an immersed 3D world. VR can simulate many senses, such as vision, hearing and touch and transforms the computer into a gatekeeper to the artificial world. Even if it is difficult to categorise all VR systems, most configurations fall into three main categories. These categories are non-immersive (Desktop) systems, semi-immersive projection systems (i.e. flight simulators) and fully immersive systems, such as head-mounted displays (HMD) [6]. See figure 2.1 for an example of how an HMD looks like.

Figure 2.1: HTC vive with controllers

2.2.1 Functional description

Most VR-products today are using an HMD-system. An HMD is a display system built into goggles that provide an illusion of a floating monitor in front of a user's face. There are two kinds of units available, single-eye units and dual-eye stereoscopic units. Single-eye units are mostly used to display hands-free instructional material, while dual-eye units are used for virtual reality applications. The HMD-system is equipped with an accelerometer and a tracking system to be able to locate the user in the virtual environment. The accelerometer also allows the user to change his field of view, by moving his head, which enhances the impression and feeling of a realistic experience.

2.2.2 Application areas

As the market and technology have developed over time, VR is now used in a various range of applications. The game industry is a great user of VR technologies and has helped to set trends in both software- and hardware technology as well as visual realism. However, manufacturing industries can be seen as the most important contributors to prosperity in the industrialised countries. The developments in virtual reality technology in the last decades have offered the impetus for applying VR to different engineering applications. For instance, product design, shop floor controls, process simulation, manufacturing planning and training are applications which in VR has been showing great potential [6].

2.3 Knowledge characteristics

This section gives an introduction to some main characteristics of knowledge. The section starts by briefly explaining the difference between tacit and articulated knowledge. The section thereafter continues with a description of knowledge transfer and sharing.

2.3.1 Tacit knowledge and articulated knowledge

Dampney et al. [7] describe tacit knowledge as the type of knowledge that is hard to describe by artefacts such as text or pictures, it is thus only contained within the mind of individuals. Unlike articulated knowledge, that can easily be shared and stored, tacit knowledge is connected to an individual's experiences and skills. To transfer this kind of knowledge, human interaction is necessary, often in terms of activities such as discussions and one-on-one communication [7]. Compared to articulated knowledge it is therefore hard to present or store in explicit form. Therefore tacit knowledge is usually obtained through closer relationships between two people. The information is then shared through voice or visualisation to the receiver. Articulated knowledge on the other hand, is often captured through written text during formal education [7]. This information could be e.g., mathematical formulas, names of chemicals or geography. Tacit knowledge is more skill-like, e.g. how to ride a bicycle.

2.3.2 Knowledge transfer and sharing

In a training context, the knowledge transfer is an important process which is a part of the knowledge sharing within an organisation. Knowledge sharing can occur through two mechanisms, personalisation and codification [8]. The first mechanism, personalisation is based on the communication between two persons. Over time personalisation allows for a higher amount of information to be transferred. This mechanism is also superior when the knowledge tacitness is higher and thus better aids the knowledge transfer. One example of knowledge with high tacitness is the skill to ride a bicycle, this knowledge is best transferred with the personalised mechanism. The other mechanism is codification, this mechanism uses technology in the knowledge transfer process. By using technology, information is stored and communicated impersonally, and the quantity of information that is shared is limited by technology. The knowledge is converted into items such as videos, documents and pictures.

2.4 Learning process

This section presents different kinds of theories connected to the learning process. This includes the learning curve and different types of learning modes connected to it.

2.4.1 Cognitive learning

Cognitive learning refers to how a person processes and reasons information. It concerns several factors such as problem-solving skills, memory retention, the perception of learned material and thinking skills [9]. The theory of cognitive learning suggests that different processes concerning learning can be described by analysing the mental processes first. It theorises that effective cognitive processes facilitate learning and new information can be stored in long-term memory. Cognitive learning can be divided into two specific theories, social cognition theory and behavioural cognition theory. Social cognition theory is based on the idea that humans learn by observing others with the context of social interactions and experiences [10]. Behavioural cognition theory, on the other hand, refers to a psychosocial intervention which is commonly used in evidence-based practice for the treatment of mental disorders [10].

2.4.1.1 Constructivism

Several views exist within the cognitive aspect of learning. One of them is constructivism, a theory that suggests that it is the interaction with the environment that constructs knowledge for an individual. The theory of constructivism focuses on using the individual's previous knowledge and new information in combination with inputs from the senses to create understanding through active learning activities. [11]. This forms a learning-by-doing process in which knowledge is constructed, this kind of active engagement aids the learning process [10]. According to constructivists in general, an active learning process means both physical and mental involvement, not just activating the body. This focuses on the learner rather than the teacher and creates a learner-centred process [12].

2.4.2 Contextual learning

An essential aspect of contextual learning is the social dimensions of learning. This indicates that humans are participants of a social context and learning can, therefore, be seen as the result of participation in different societies. This type of learning, according to Wenger [13], is grounded on the fact that 1) humans are social beings, 2) knowledge is a matter of competence, 3) learning is connected to specific situations or contexts and finally 4) meaning is the motivation strength for learning. The importance is that learning is connected to specific contexts or situations and that learning often associates to elements of collaboration with other people. It can basically be seen as the outcome of activities performed in certain situations where previous experiences are used as resources. Since contextual learning is connected to explicit contexts, historical, cultural and material aspects have an influence on the learning in social situations or practices.

2.4.3 Learning curve

Operators simply learn their tasks by executing them. Hoedt et al. [4] state that the more a certain task is performed, the experience level increases. When the experience is increased, the required time to complete the task will decrease. Wright [14] introduced this phenomenon and called it the learning effect. A more visual method to illustrate this phenomenon is by a learning curve, where the required time to complete a task is shown as a function of the increasing production capacity, see figure 2.2.

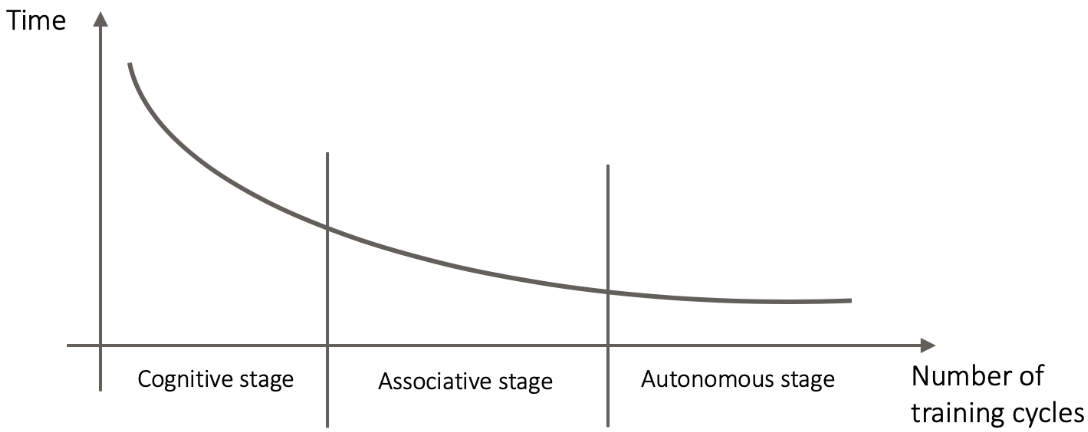


Figure 2.2: Learning curve. Adopted from [15]

Fitts et al. [15] describe the learning curve in three stages. The first stage, called the cognitive learning stage is where the learner attempts to understand the task and what it requests. The learner converts the skill into a form that later supports the process to generate the wanted behaviour. The associative stage is the second stage where initial understanding is converted to practical acting. If there is any case of cognitive tasks, like solving an equation, mind patterns are developed. Anderson [16] describes this stage as a transition stage where knowledge is practised and converted into a procedural form. The final and third step described by Fitts et al. [15] is named the autonomous stage. This stage is based on an on-going improvement in the performance of operations. One task can be carried out with less processing, meaning it can occur while other perceptual or cognitive actions are taking place. During this stage, new learning can occur as well. Examples can be well-practised skills, such as walking, which the person has no problem doing while talking. According to Anderson [16], this is the procedural stage which constitutes a final transformation of declarative to procedural knowledge.

2.4.4 Learning modes

Mattson et al. [17] presents three assembly modes, based on Sheridan's five interrelating roles of system operation [18], that an operator will move through during a workday. These modes are called learning, operational and disruptive. The learning mode is particularly considered as an important aspect of assembly as this is where the operator learns new tasks and technologies [19]. It is also an important phase as the future operators need to learn new tasks and technologies every time a new product is introduced. Mattson et al. [17] claims that both cognitive learning and contextual learning are necessary to achieve the wanted competence, i.e. the correct assembly sequence. Cognitive learning emphasis more on the theoretical aspects while contextual learning relies on practical work and experience. The operational mode, presented by Mattson et al. [17], is the most common mode in final assembly. Examples of tasks that an operator performs during this mode could be to monitor machines, handle material or teach i.e. program operators or robots. These are tasks that are more of day-to-day work. The third mode, disruptive mode, is considered as an important part of complex assembly according to Mattson et al. [20]. The disruptive mode includes tasks that are unknown to the operator e.g. problem solving, handling disturbances such as lack of components or machine failures, or disturbing events like surrounding noise.

2.4.5 Forgetting Curve

Herman Ebbinghaus was a German psychologist who established studies of memory, learning and the exponential nature of forgetting. This also included the speed with which information is lost when no attempt to retain it exists. Ebbinghaus is most recognised for his forgetting curve where he claims that humans tend to frequently halve their memory of recently learned knowledge in a matter of days or weeks if they do not actively review the learned material [21].

The forgetting curve can be described through the equation 2.1.

$$R = e^{\frac{-t}{s}} \tag{2.1}$$

Where R refers to memory retention, S refers to the relative strength of memory and t refers to time. The visualisation of the curve can be observed in figure 2.3.

Ebbinghaus discovered the forgetting curve to be exponential in nature. At the time of learning, memory retention is 100 %. However, memory retention rapidly drops to 40 % within a few days. After this drop, the declination of memory retention flattens out. The forgetting curve is exponential due to the fact that memory loss is high and rapid within the first day of a learning situation. There are several factors affecting the rate of forgetting such as the meaningfulness of information, representation of the information and physiological aspects i.e. stress and sleep.

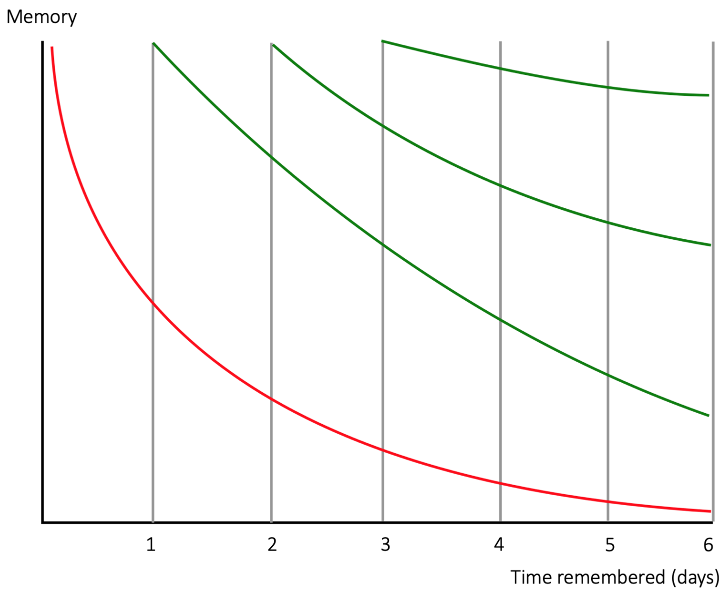


Figure 2.3: The forgetting curve. From [22]

2.5 Further aspects of learning

This section presents further aspects related to learning such as behaviour and theories behind motivation.

2.5.1 Behaviour and knowledge levels

Mattson et al. [17] describe three knowledge levels based on Sheridan's five interrelating roles of system operators [18]. These levels are named skill-based, knowledge-based and rule-based behaviour. The major distinction between these knowledge levels is the degree of automatism in the execution of tasks [4]. The first one, skill-based behaviour, requires less control when performing a task if an intention is defined, this forms an unconscious behaviour. The outcome is described as both smooth and automated. One example of skill-based behaviour is riding a bicycle because once you have learned how to do it, little focus on control is needed. When the task is performed autonomously, cognitive resources can be used for more demanding things like problem-solving. The rule-based behaviour requires more focus since it depends on signs in the environment and stored rules from previous scenarios. The signs are connected to specific behaviour and need to be activated before they can be processed. Finally, knowledge-based behaviour is the result of an unfamiliar situation and how we act from it. This behaviour is identified as conceptual thinking and trial and error, it requires the attention of the human and a delimitation is thus that humans can only focus on a limited amount of things at a time. This behaviour is, therefore, the most cognitively demanding [17].

2.5.2 Motivation

Fasth et al. [23] explains the concept of motivation as an individual's choice to engage in an activity together with the level of intensity of effort or persistence in the activity. Motivation is generally divided into three categories: intrinsic, extrinsic and social motivation [24]. Intrinsic motivation defines motivation that is engaging due to the activity itself and not for some kind of external reward, e.g. money. According to Osterloh [25], intrinsic motivation is the most crucial part when tacit knowledge is being transferred in and between groups. Extrinsic motivation refers to the situation when an individual is motivated to perform a task to either receive a reward or avoid punishment. Lastly, social motivation denotes the human need to socialise with other human beings and to receive acceptance from them. These are interactions that Osterloh [25] regards as social behaviours and which address other people with the intention of getting a reaction.

2.5.3 Gamification

Gamification refers to the application of certain elements of game playing, e.g. point scoring, rules of play, competition with others to encourage engagement with a product or service. The intention to use the concept of gamification is to utilise the characteristics a game has set up to how to deceive users, not the game itself [26]. What is desired, apart from the simulated engagement, is to endorse the commitment of individuals, focus on the participating points and to give rewards for it. Pereira et al. [26] explains that exploiting the techniques of gamification for the purpose of bolstering qualifications, is a common practice among companies. Fasth et al. [23] explains games as an interactive system that respond quickly to a user's actions which keep them motivated and engaged. Digital games are able to combine and trigger the three types of motivations simultaneously and get a user involved to interact with a product. Extrinsic motivation can be achieved by giving rewards such as levels or points in the game. An example of an intrinsic reward is to give the player autonomy e.g. to allow feelings of competence or sense of control in the game. Finally, social motivation can refer to the use of collaboration and competition between players [27].

2.6 Training within Industry

Training within Industry (TWI) was founded in the United States in the 1940s. The main mission of TWI was to help industries become aware of how they could get out more material and in a more efficient way. The institute delivered hands on methods for a more efficient production. One of the well-known methods used still today is the Job Instruction 4-step Method (JI 4-step Method) described in section 2.6.1.

2.6.1 Job Instruction 4-Step Method

The JI 4-step Method was invented by the TWI institute during the second world war. The main purpose at that time was to train millions of unemployed people in order to increase the production rate of military goods. The TWI concept was adopted by the Japanese government at the end of 1945 and has later become a central part of the Toyota Production System. Graupp and Wrona [28] claims that the JI 4-Step Method, when applied properly, can assure a successful training experience every time. Further, this method functions quickly and efficiently while simultaneously ensuring that the trainee knows how to do the job safely, correctly and conscientiously. The JI 4-Step Method is illustrated in figure 2.4.

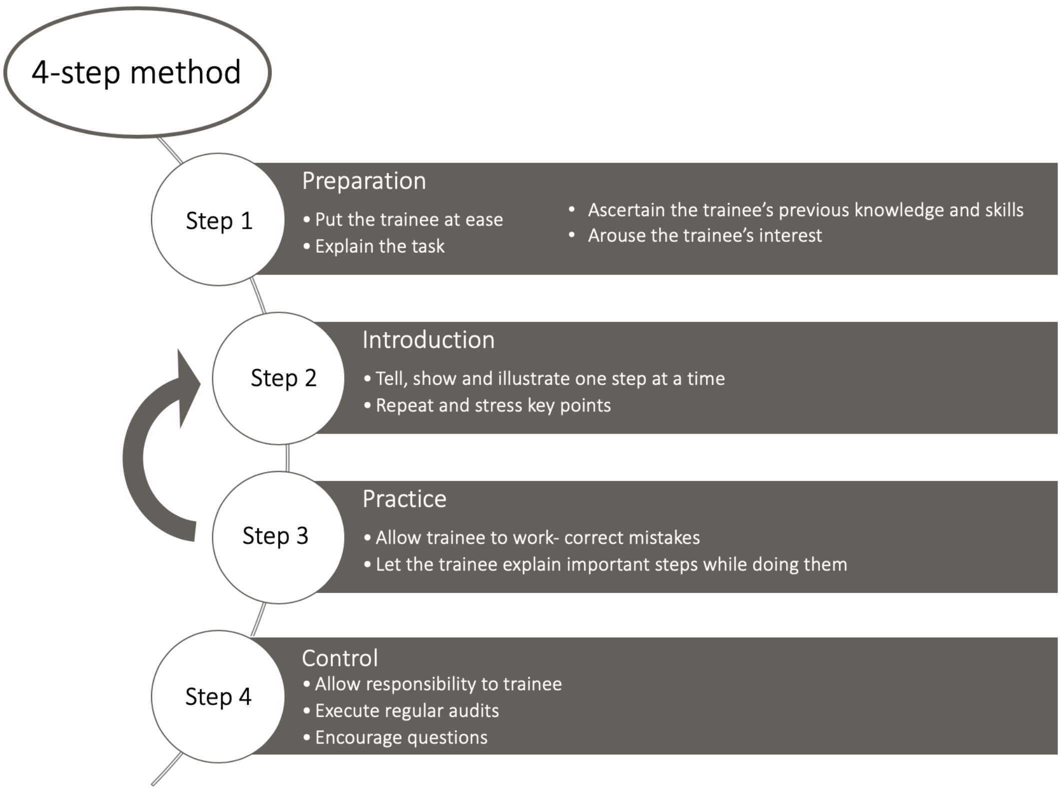


Figure 2.4: The job instruction 4-step method

The first step aims to prepare the trainee into the correct frame of mind by explaining the task in detail and putting the trainee at ease. Anxiety and uncertainty create barriers to communication and could cause a trainee to miss important points. Graupp and Wrona [28] points to the importance of knowing that every person is unique, meaning that trainers consequently need to consider attitude and demeanour at the time of training. This is crucial in order to ensure that the trainee is receptive to learning their job. Another important aspect of the first step is to find out the previous knowledge and skills of the trainee. This allows the trainer to evaluate and adjust the amount of instructions needed to teach the task properly.

The second step refers to the introduction of the task itself. The trainer demonstrates the task in detail and tells the trainee what is demonstrated. Graupp and Wrona [28] claims that most people do not learn a task by seeing it demonstrated one time. A second demonstration allows the trainee to expect the next time around and helps to understand what they saw at the initial demonstration. The trainer introduces the trainee to key points of the task that are not readily apparent. The third step is where the trainee starts to perform the task. This step is important to not rush into until step two is fully completed. The trainee must fully understand the important steps and key points before this step is initiated. The trainee performs the task while explaining it during observation from the trainer as long as necessary. The fourth step refers to the time when the trainee has repeated the task several times and is able to work independently. The trainer liberates full responsibility to the trainee but accomplishes regular audits at fixed intervals.

3

Methods

This chapter describes the methodology used for this thesis. The overall research approach is presented. The approach constitutes several steps that are described in the following sections.

3.1 Research approach

Empirical research was used as the foundation for this thesis. According to Flynn et al. [29], empirical research can be described as using observations from the real world to form knowledge rather than using experiments in a laboratory. Flynn et al. [29] introduce a systematic approach for empirical research that was adopted in this thesis. The process consists of six steps: Establish the theoretical foundation; Select a research design; Select a data collection method; Implementation; Data analysis and Publication [29]. The implementation step was not performed as described by Flynn et al. [29], it was incorporated in the data collection method. The final step of the process, publication, refers to this thesis. The process is visualised in figure 3.1.

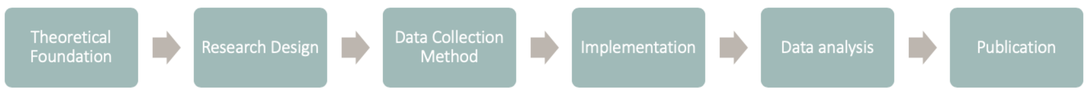


Figure 3.1: Systematic approach for empirical research. From [29].

Further, the research approach chosen for this thesis was qualitative research. This approach is common for a number of disciplines where the process is of an emerging character [30], [31]. Qualitative research is a general term that covers a wide range of techniques and philosophies. This approach allows for the examination of human experiences in detail by using research methods such as interviews, observations and visual methods [32].

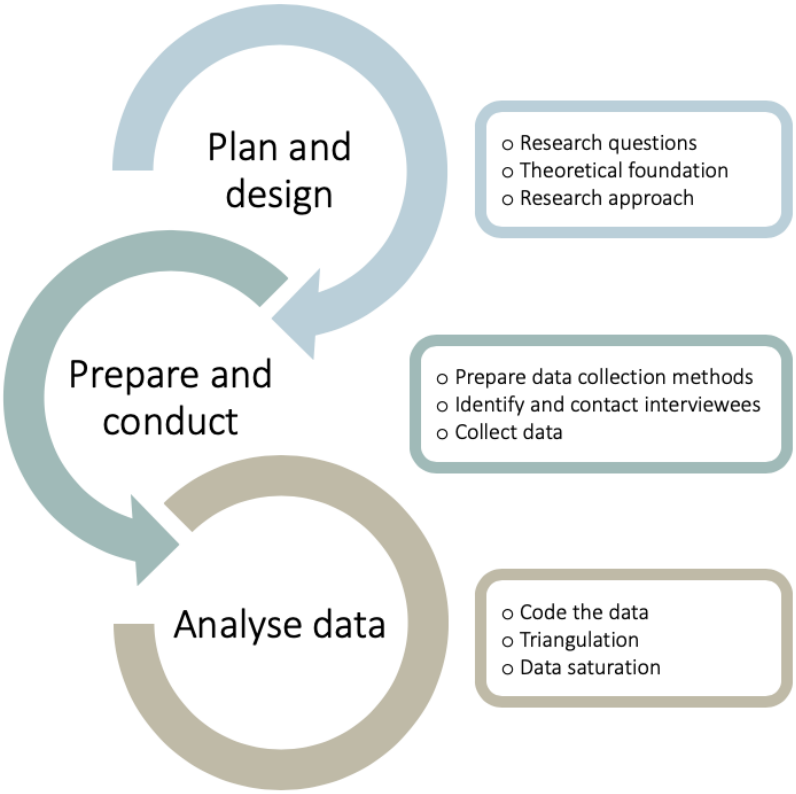


Figure 3.2: Qualitative research process inspired by [32]

The research process in this thesis was cyclic to its nature and is illustrated in figure 3.2. It was inspired by the qualitative research cycle presented by Hennink et al. [32]. The emergent design is apparent, i.e. an initial plan could not be formally established. Thus the research process is continuously evolving and adapting forming a repetitive procedure. The first step is about planning and designing the foundation of the research, including formulating research questions and establish a theoretical framework. Preparation and conduction is the second step and refers to the collection of data. The collected data is analysed in the last step, data analysis. This constitutes summarising and categorising the data to further develop the theory. These steps are repeated until the result is finalised.

3.2 Theoretical foundation

Flynn et al. [29] states that the foundation for scientific research is theory. There are two ways in which an empirical study can address theory [29]. The first approach is theory verification, that is the method of first generating a hypothesis and then testing it. The hypothesis can be of a scientific origin such as previous studies or it can be based on the researchers own ideas and basically be pulled out of the air.

The test of the hypothesis is the important part of theory verification while the hypothesis itself and its origin is of less interest [29].

The other approach is theory-building, which was chosen for this thesis. The base of this approach is not a hypothesis and the collected data is used differently. The study is based on, for example, some assumptions or a perceived problem, however, the foundation still constitutes prior theory [29]. The process of theory-building starts with an initial theory. Data is collected in order to expand the initial theory. The initial theory is thus not confirmed or denied, rather developed and enhanced [29]. The new theory is thus grounded in data. More data could be collected to elaborate the theory even further and the process is iterated until a final theory is proposed [29]. For this thesis, the theory was the workflow for virtual training. The initial theory was a tentative workflow that was further elaborated using collected data.

3.3 Research design

The research design chosen for this thesis was a single case study. A case study is an empirical analysis that investigates a current phenomenon in depth within the real-world context. This is especially evident when the boundaries between phenomenon and context are not clearly apparent [33]. The purpose of conducting a case study in this thesis was to get an understanding of the real-world context and to involve important contextual conditions pertinent to the case. Another reason for conducting the case study was to have a case to demonstrate and exemplify the results. The research methods used for data collection are further described in section 3.4

3.4 Data collection methods

This section describes the various methods used to collect data. The methods are derived from qualitative research and case study approaches.

3.4.1 Literature study

A literature study was conducted to answer the subquestions (SQ.1-SQ.4), presented in section 1.2, and to form a theoretical framework. The literature was used mainly to form an understanding of the current state within the research scope. Initially, keywords related to the subquestions were identified and combined to find relevant content. Examples of some of the keywords used:

- Virtual Reality

- Virtual Training
- Manual Assembly
- Assembly training
- Gameification
- Usability
- Learning environment

In order to comprehend the collected data, it was analysed in multiple steps based on the methodology of grounded theory further explained in section 3.5.1. This process is visualised in figure 3.3

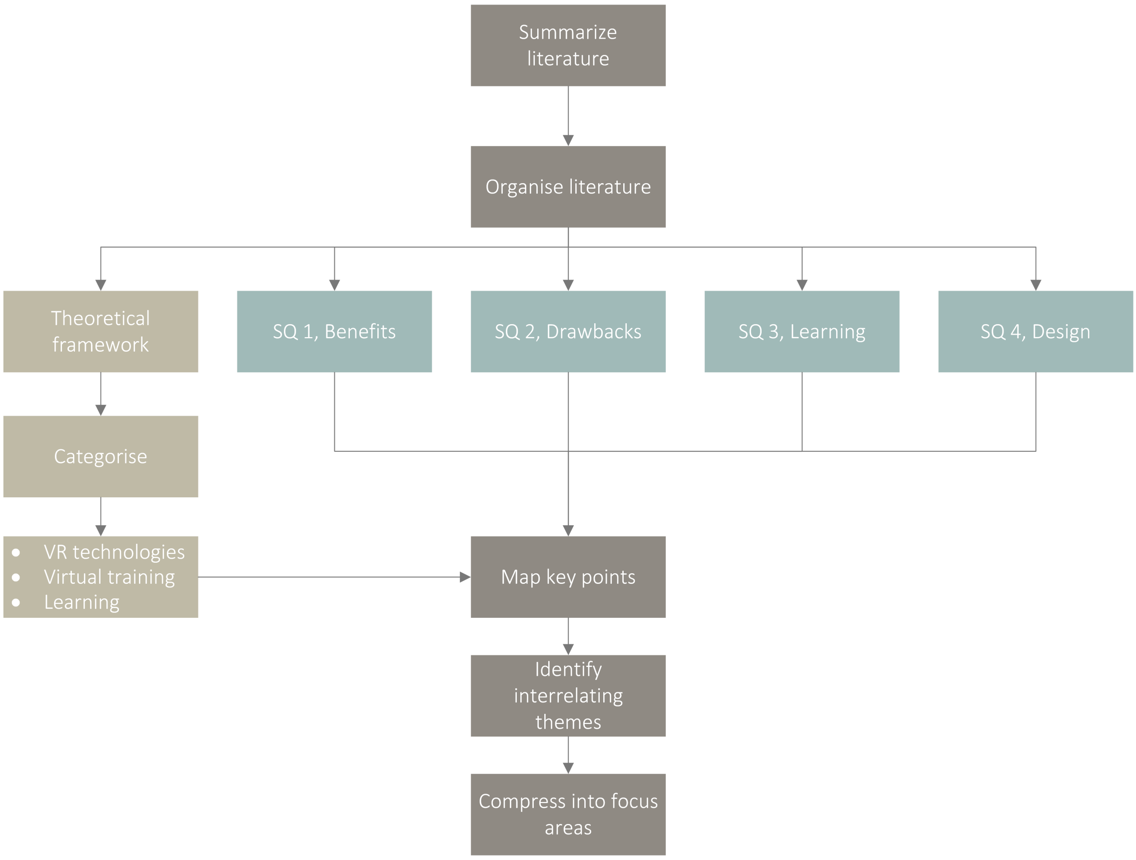


Figure 3.3: Literature study visualised process

The first step of the process consisted of summarising the literature to get a comprehensive and holistic view of the data. The summary was combined into a document and colour coded based on subquestions and theoretical framework topics. The data related to the theoretical framework was further categorised into themes such as VR technologies, virtual training and learning. The identified key points were mapped into groups using post-it notes. Every group was analysed to find interrelating facts and statements between different authors. The aim was to narrow the range of data since the total collected amount could not be included [34]. Finally, the data within each group was compressed into focus areas to be included in this report.

3.4.2 Interviews

Denscombe [35] presents three ways to structure an interview. The first one is structured interviews which consist of a set of predefined questions prepared by the researcher. The questions are phrased in a way that encourages limited-option responses. This method allows for a standardised collection of interview data especially useful when a high number of interviews are conducted [35]. The second way to structure an interview presented by Denscombe [35] is semi-structured interviews. Questions are predefined in the same manner as for the structured interview, however, the topics can be addressed in a more flexible manner. Thereby allowing the interviewee to freely elaborate on the topics resulting in more open-ended answers. The third way of conducting an interview is the unstructured interview [35]. The focus is not to answer a set list of questions, rather the researcher introduces the topic of interest to the interviewee. This allows the interviewee to share their own ideas and thoughts with the least amount of directing desired [35].

The semi-structured interview was chosen for this thesis. This approach allows for developing the interviews during the project and adapting questions based on previous interviews. Conducting interviews this way is related to grounded theory and qualitative research which is used in this thesis [35]. The majority of the interviews were recorded and transcribed. The rest were documented by taking notes during the interview.

The purpose of the interviews was to gather information on current and previous research within virtual training, understand the training for operators at the Tuve plant and the expectations from the production. Interviewees were chosen to capture the experiences and perspectives of virtual reality from multiple sources. Therefore employees within Volvo Group as well as people external to the organisation were identified. The initial interviews were used to select new interviewees until the collected data was sufficient and all questions were answered.

The interviewees can be categorised into three groups: Research, Production and Internal research. The interviewees are presented in further detail in table 3.1. There are no direct guidelines in qualitative research for testing the adequacy in order to determine the sample size. In contrast to quantitative research where formulas can be used, qualitative research points out that signals of saturation might be determined by investigator proclamation and evaluation of comprehensiveness of the obtained results. The qualitative data obtained might at first seem diverse and disconnected but in the process of saturation, it starts to form patterns and themes. Morse [36] claims that there are no rules of the amount of data required in each category to form these themes and patterns. Rather, he stresses the importance of giving all data equal attention in the analytic coding procedure.

Table 3.1: List of interviewees and their expertise

Interviewee	Knowledge of interest	Background
Research		
Researcher 1	Experience in virtual training	University West
Researcher 2	Experience in virtual reality implementation towards industry	Chalmers University of Technology
Researcher 3	Experience in developing virtual environments based on point clouds. General experience within virtual reality.	Chalmers University of Technology
Researcher 4	Production ergonomics within industry, especially automotive industry. Knowledgeable within manual assembly and assembly complexity.	Chalmers University of Technology
Production		
Production 1	Responsible for training of operators at a department within the Tuve plant. Experience from projects in virtual training.	Volvo GTO, Production leader
Production 2	Responsible for training of operators at a department within the Tuve plant.	Volvo GTO, Production leader
Production 3	Trainer at the introductory training that all operators complete before employed and assigned to a department. Knowledge in training and general assembly operations.	Volvo GTO, Training Facility in Tuve, Trainer
Internal research		
Internal research 1	Experience from projects within training using augmented reality	Volvo GTO
Internal research 2	Experience from projects within training using digital tools.	Volvo GTO

3.4.3 Observation

Multiple study visits were conducted at the Tuve plant to gather data through observations. The study visits included both the bogie cross member subassembly and the training facility. The aim of the study visits was to understand the production first hand and observe the training environment at the training centre. This established an understanding of the current state and existing conditions regarding the training and production environment. During the visits, notes were taken and questions were asked to gather relevant data.

3.4.4 Documents

Internal documentation was studied to get acquainted with the current standards and procedures used in the production. Document categories included standard operation procedures (SOP), assembly instructions, operator certification and sequence sheets.

3.4.5 Audio and visual materials

Several visual sources of information were studied within both production and virtual training development. The material consisted of video demonstration and previous software projects within virtual training. The purpose of this study was to arouse ideas and thoughts about the next step in the development of virtual training.

3.5 Data analysis and validation

This section briefly describes the methods used to process and analyse the collected data. Methods to ensure the validity of the collected data are also briefly presented.

3.5.1 Grounded theory

Grounded theory is a method that develops theory from collected data rather than evaluating ideas presented prior to the collection and analysis of data [37]. Thus, the theory is grounded in the observations of participants in the social world [32]. This process is based on a flexible approach to data selection. Sources are selected throughout the process to enable the exploration and cultivation of emerging ideas [37]. Data collection and analysis are not executed in a linear manner, rather, they are intertwined in a circular process [32]. The data analysis is based on coding data to form categories conceptualising the information. The coding is performed in three stages, open, axial and selective [37].

The first stage of coding data consists of comparing and categorising it. Categories are created from the data itself and are not relying on prior theory [37]. At this stage, the goal is not to identify the most important findings, the purpose is rather to generate a high number of categories stimulating new ideas [37]. The next stage of coding, axial coding, connects categories to create a frame of reference and thereby integrating them. The final stage, selective coding, focuses on a core category. Categories are integrated further to create a comprehensible overview of the central concept. This stage finalises the data analysis by forming a framework around a chosen core category [37].

3.5.2 Triangulation

Triangulation is an approach that combines multiple methods for data collection and analysis in qualitative research. The idea is that multiple approaches aid the understanding of the studied phenomenon [38]. The approach is often used to strengthen the findings by identifying and probing various dimensions of the studied topic. Triangulation can be used in multiple ways; triangulation of methods, investigator triangulation, theory triangulation and triangulation of data sources [38]. The approaches used in this thesis was the triangulation of methods and triangulation of data sources.

Multiple methods were combined to get a more complete understanding of the researched area. Interviews and observations were combined to get multiple perspectives spanning different time periods. This process aided the triangulation of data sources which consisted of interviews, observations, documents and audio and visual materials. Every source contributes to a unique understanding of the studied phenomenon [38].

3.5.3 Data saturation

Data saturation is often defined as data adequacy. It could be explained as collecting data until no new information is obtained [36]. In qualitative research, there are no guidelines or rules for estimating the amount of data required to achieve saturation compared to quantitative data where formulas can be used. Saturation in qualitative research might rather depend on investigator proclamation and the comprehensiveness of the results. Qualitative data might initially appear as diverse or disconnected but, in the process of saturation, forms themes and patterns which begins to make sense. Morse [36] claims that there are no rules that determine the amount of data required in each category but stresses out the importance of giving each group the equal amount of consideration in the analytic coding procedure. The frequency of each specific occurrence must be ignored as saturation refers to eliciting all forms and types of occurrences. It is more important that the researchers have "heard it all" rather than hearing things repeatedly over and over which could lead to a false sense of saturation. What is important in data saturation is the richness of the data, not the frequency something stated. Morse [36] denotes that this principle is crucial to understand saturation. Saturation occurs faster depending on how restrictive, narrower and clearly delineated the data is. This approach was used during the whole procedure of collecting and analysing data in this thesis.

4

Current research and production

This chapter presents the results of the preliminary study aimed to answer the first research question. The results of this chapter are the foundation for the development of the workflow. Firstly, the main findings from the literature study are presented by answering the subquestions introduced in section 1.2. Secondly, the use case is described in terms of the product and production flow. Finally, the current training process is presented.

4.1 Literature study

This section answers the subquestions stated in section 1.2. The answers reflect the main findings identified by patterns and different themes from the literature.

4.1.1 What are the benefits of using VR?

A lot of research has been done on virtual training as the opportunities within the area are acknowledged for years. The most recognised areas of use are within aerospace and chemical industries [39],[40]. Gorecky, Khamis & Mura, [41], argue that wearable devices such as head mounted displays show great promise in virtual reality and augmented reality (AR) training. VR-based training, compared to traditional learning approaches, can boost the ability to make abstract problems more concrete. Chen [11] presents the virtual environment as a cognitive tool that is capable of making imperceptible things perceptible as well as the opposite. He further argues that in a virtual environment the learner allows to visualise and understand complex structures that would otherwise remain hidden. Learning through VR is vivid, supports theoretical thinking and helps sharpen students' operational skills [10]. A learner can in a virtual environment directly interact with objects, test ideas and observe the results in real time. This consequently shows that VR fits well into social cognition training intervention [10].

A study made by Langley et al.[42] suggests that a virtual training system has the capability to provide training that produces greater retention of procedural knowledge which therefore requires less intervention from the trainer. This is an important finding since any mistakes or errors made in the assembly that causes a stoppage of the production line is costly in terms of both money and time for the company. Virtual training does not require physical prototypes but instead provides an efficient solution when virtual models of the workspace, parts and tools are available. Vélaz et al. [43] therefore argue that the introduction of a training program for a new product requires little additional effort meaning that several scenarios can be trained in a short time span.

The opportunity to bring the operator into the virtual commissioning allows for operator training before the real start-up of the manufacturing. A virtual training system can be used at any time without the need for a real setting and consequently without the costs for downtime of the production [44].

4.1.2 What are the drawbacks of using VR?

A lot of the design and implementation of VR supported learning are based on the technical aspects but lack well-defined learning theories or custom designed models that would serve as foundation and guidelines [5]. There is simply a missing learning model that considers both the pedagogy and the technical affordance of VR. Hoedt et al. [44] state that the learning transfer during a virtual training is most commonly limited by the fact that the user never performs the exact same operations. They further conclude, from this fact, that virtual training seldom improves an operator's behaviour on the skill level.

Gorecky et al. [41] present two main reasons for the rare establishment of virtual training. The first reason, in this case, would be the lack of user acceptance. They mean that the currently available processes are neglecting convenient and affordable market solutions. Further, they claim that there is no elaborated training process which synergistically combines virtual training with hardware training as well as integrating it into existing organisational structures. The second reason is that relevant data for virtual training are often widespread over different systems in a company. It requires a lot of effort to collect the relevant data and defining training scenarios which have conclusively outbalanced the possible benefits of virtual training. Data is available but Gorecky et al. [41] claim that the main problem is that a methodology for integration and reuse of existing data structures is missing.

Another reason for the rare establishment of virtual training is that most evaluations are conducted in a limited laboratory environment with low complexity and with typical LEGO Duplo assembly tasks [45]. The technology used in virtual training must instead be evaluated under existing conditions to conceive all influencing factors.

4.1.3 How is it possible to involve learning aspects in VR-training?

Hoedt et al. [44] divide errors into two main groups as knowledge-based errors or craftsmanship errors. The motivation of this division is the ability to compare systems on both knowledge transfer and motor skills training. The most common case, however, is that the motor skill training is done online on the real assembly line since the realistic use of tools is not completely visualised in the virtual assembly.

Gorecky et al. [41] claim that the most important knowledge components are clustered in different semantic classes. They are talking about Object, which refers to which parts will be assembled and how they look like. Local context is about where the parts need to be placed. Instrumental context explains which tools must be used for the assembly. Conditional context simply refers to which specific conditions the work will be conducted. Finally, the last class is called consecutive context and states which sequences need to be followed. These classes could serve as a guide and help to get the learning concept into the training in VR. In some ways, this resembles a framework designed by Mayers and Fowler[46]

They describe a framework which offers a principled way of relating a concept like immersion to the contrasting ways of understanding a learning experience. This framework was designed and aimed to simplify the complexity of learning at the psychological level into three important stages. This framework is used to characterise a learning experience in one of three ways. The first stage will encounter the learner with some kind of explanation that provides an opportunity for a new concept to be formed. Basically, this stage describes what is to be learned, in the case of skill learning. Regarding conceptual learning, this stage should give an initial understanding of the concept to be formed. The second stage requires the learner to deepen their understanding, start to interact and explore and ask questions. At this stage, the learner's actions control the information flow. Third, Fowler and Mayer [46] designed a stage of learning as a dialogue where the learner can test their understanding through interaction and discussion with others. This stage is designed to acknowledge that learning is in some ways situated in a wider social context. Fowler [47] however, explores whether a three-dimension virtual learning environment is able to create new learning experiences that address these stages of learning. He points to the importance of the word "new" as he states that innovative technologies should not only be used to emulate current practices but innovate, if possible, new pedagogically sound practices.

4.1.4 What aspects are important to consider when designing virtual training with VR?

There are several aspects to take into consideration when designing a virtual training environment. Interaction design is an important factor that influences a big part of the system. The interaction design of the virtual training system does not only affect user acceptance but also influences knowledge transfer and the overall success of the system [41]. Zhou et al. [5] suggest two sessions in designing and implementing an application of computer assembly, the learning session and the game session. Research by Gorecky et al. [41] showed that game-based user interaction offers an intuitive and engaging user interface and increase user involvement and knowledge transfer.

Hoedt et al. [44] present other interesting and important aspects to take into consideration in the design of a virtual training process. Firstly, they argue that a decision has to be made whether the training is knowledge-based or skill-based. Knowledge-based training, where knowledge is transferred by the training system, requires the product to be challenging enough to make sure that a positive effect is noticeable when a trainee gets training. On the other hand, they argue that if the product is too complex, a large part of the learning transfer could be lost due to a cognitive overload of the trainee. If this is the case, the trainee must be supported with information during the assembly. Syberfeldt et al. [48] explains that since learning is a dynamic process, they believe that the information content during training must be dynamic and individual as well. To dynamically customize instructions is however no easy task. A decision must be made for each task and operator, in real time, what information is important to show at that moment as well as what information not to show. Too much information might be frustrating and could impose a high cognitive load for the operator [48]. Presenting the operator with the right information and knowledge needed is also important to be able to handle many different work situations [49].

A study made by Zhang and Sotudeh [50] revealed that non-realistic or inappropriate feedback using visual cues had a negative effect on task performance and could easily frustrate the user. It is an important aspect to bear in mind when designing training in VR. Further, Etemadpour et al. [51] indicated that tasks which focus a smaller part of the immersive environment improve in performance when using VR. User performance, in fact, goes down for global tasks which require a user to comprehend a whole 3D environment.

Chen [11] clarifies the important statement that tools do not teach by themselves. They have to be prudently and effectively implemented to assist in the learning process.

4.2 Case at Volvo GTO

The developed workflow will be connected to a case chosen by Volvo GTO previous to the start of the thesis work. The case is the assembly of the bogie cross member. This section describes the bogie cross member and the production flow of the subassembly.

4.2.1 Product

The case is limited to the subassembly of the bogie cross member. This product is a part of the structural frame of the truck. The main frame consists of two chassis beams that span the full length of the truck. The two beams are connected by several cross members, among them the bogie cross member.

The bogie cross member is located at the back of the truck between the rear wheels, see figure 4.1. The part gives the chassis rigidity and is an attachment point to other components. These include, for example, control systems for brakes and suspension, cabling and an air tank for compressed air. There are several variants of the product but the main components are similar. It is generally smaller differences such as screw lengths that vary. A fully equipped bogie cross member can be seen in figure 4.2.

Figure 4.1: Location of bogie cross member on the chassis, from [52]

Figure 4.2: Fully equipped bogie cross member, positioned upside down

The assembly of this product is critical since errors affects the whole assembly line. The reason is that the frame and cross members are joined in the first section of the main assembly line. Errors might not be detected before the cross member is attached to the main beams using bolts and rivets. Hence, errors are detected further down the line when more components are attached which makes corrections harder. Worst case scenario is if the cross member needs to be removed, this process requires the rivets to be drilled out which is very time consuming and might damage the chassis.

4.2.2 Production flow

The production system at the Tuve plant consists of several subflows feeding the main assembly line. In the first section of the main assembly line the chassis of the truck is positioned upside down for easier access. One of the subflows of the main assembly line is the bogie cross member assembly. This section is divided into four stations two of which are parallel and identical. The flow is L-shaped and can be studied in figure 4.3

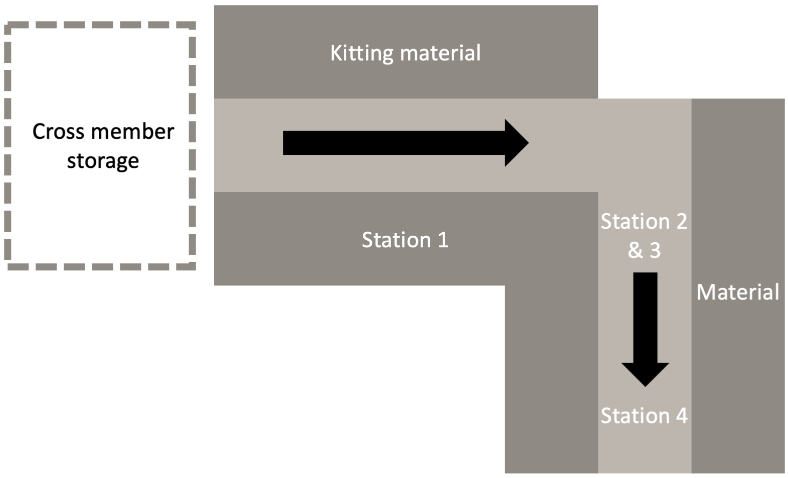


Figure 4.3: The production flow of the bogie cross member subassembly

At the first station, the correct bogie cross member is picked and put on a trolley, see figure 4.4. A kit is prepared using a pick-to-light system and the parts are placed in a trolley that is moved together with the cross member. Some parts from the kit are used at station one and the rest is used at the following stations. The rear chassis I/O module (RCIOM) is programmed. Other parts are prepared and pre-assembled before installation on the bogie cross member. The RCIOM is mounted after necessary components have been prepared and assembled before. An ID-card is prepared and put on the beam using magnets, finally, the trolley is moved to the next station.

Figure 4.4: Bogie cross member on the trolley used in subassembly

The second and third station are parallel and identical since the tasks take twice the assembly time. At these stations, some components from the kit are mounted thus the major assembly is the cable harness. First, the cables are prepared on a table where they are tied together using zip ties. The prepared cable harness is placed and fastened on the cross member and various connectors are attached. Finally, the cover over the RCIOM is mounted.

At the fourth and last station, the electronic-controlled brake system (EBS) modulator is mounted and various screws are fastened. The second EBS-modulator is mounted and fastened. Some variants have several valves mounted. Cabling is attached and connected as well as the air tank. Finally, the cabling is bundled together and fastened on the top of the cross member and the ID-card is placed on top of the air tank. The sub-assembly is complete and the bogie cross member is ready for the main production line.

4.3 Current training of operators within Volvo GTO Tuve

This section describes the current state regarding the training of operators at the Tuve plant. It is based on interviews and observations from one section of the factory. Therefore this description is not complete and other scenarios and procedures might occur. First, the training facility at the Tuve plant is described. Secondly, the training process of a new operator at a department is briefly explained. Finally, some key elements of the training are further described.

4.3.1 Introductory training

The training facility is located at the Tuve plant and provides a variety of training programs for the employees. The focus is mainly on product, process and quality. All new operators participate in a three-day introduction program before they are employed and assigned to a department. The training program is performed in groups with up to 14 participants. There are different sessions focusing on various subjects, such as safety, product knowledge, tools and material. The major focus of the training is safety, how to behave in the factory and what not to do. The trainees are also introduced to the standard operation sheets, sprint and sequence sheets. The idea is that the trainee will recognise these, and know what kind of information they contain when they later start at their department. The Volvo production system is explained during the training. The theory is mixed with hands-on experiences where the trainees get to use the most common hand tools. The purpose is to familiarise the trainees with the equipment, however, they are not expected to obtain any assembly skills. The training is finalised by a theoretical test on product knowledge, Volvo organisation, safety and so forth. To make sure that the trainees meet the requirements and are approved on the test, the learning outcomes of every part of the training are always explained and repeated to aid the learning.

After the introductory training at the training facility, the trainees wait to be employed and assigned to a department. This could take several weeks depending on the employee turnover and demand for new operators.

4.3.2 Training process for new operators

The current training of operators for a department is based on a standardised process. This process is presented in a document that is used to certify the new operator. The certification is the final step of the training and allows the operator to work unsupervised at the production line. The process consists of four steps that each needs to be approved. First, the new operator is welcomed by the production leader to their new department. Rules and code of conduct are repeated and the operator is familiarised with the department and its location within the plant. The operator is introduced to the team leader and the safety representative as well as the chosen tutor.

The new operator is assigned to a station within the team, usually one with lower complexity. Initially, the focus is to get to know the team and routines such as when to take breaks. The second step is to get familiarised with the station and its location at the department. The operator is introduced to standardised work and the training procedure. The work tasks, tools and material used for the station are explained and demonstrated. What should be performed, how and why are the key aspects taught at this stage. Standard operation sheets, sprint and sequence sheets for the specific station are included. The operator is approved when the understanding of the station is sufficient according to the certification document. The next two steps aim to let the operator practice with supervision. First, the tutor performs each task and explains what is done. The operator performs the tasks monitored by the tutor who corrects mistakes. At this step, the focus is to support the operator and ask questions to evaluate the current knowledge. This step is complete when the operator can perform tasks fairly and respects all safety and quality aspects. Before moving on to the next step documents are signed for some stations. These include sequence sheets, standard operation sheets and one-point lessons. The documents are signed to ensure that the operator follows the standards and understands them. When this is done the training continues to the next step. The operator performs each task of the station for multiple takts while the tutor observes the actions and corrects any mistakes similar to the previous step. The operator is certified for the station when they successfully perform each task to standard regarding safety and quality, within the takt time and fulfil every criterion in the certification document.

The training period has no set time schedule and is different depending on multiple factors. Complexity at the station and product variants as well as the operator's previous experience and learning pace affect the process. The training is adapted to every individual and can span from two days up to more than two weeks.

5

Workflow for virtual training

This chapter describes the developed workflow for virtual training which answers RQ.2. The chapter starts with an overview of the structure, symbols and interfaces used in the flow. The person participating in the training is in this chapter named as the trainee. The trainer is the person that welcomes the trainees and is available for support during the whole session. Finally, the main flow is presented and each subflow explained.

5.1 Structure of the workflow

The workflow is structured as a set of processes and subprocesses. All symbols included in the flows are listed in table 5.1. One important distinguishment is the difference between data and information. Information refers to processed data that is presented to the trainee. Data is generated or collected from other systems. For example, data is collected during the training session in the form of numbers and then analysed and presented to the trainee as information in the form of graphs and scores. Information can be described as data that has been processed and presented for a specific purpose.

Table 5.1: Explanation of symbols used in the workflow

Symbol	Explanation
	Interface
	Descison made by the system or the trainee
	Information
	Data
	Subflow
	Level unlocked
	Desktop-based environment
	VR-environment
	Direct connector
	Data connector
	Trainee interaction
	Unlocked level

5.2 General interfaces

These sections present examples of interfaces included in the workflow. The interfaces function as a link between the trainee and the system. These interfaces are created to support the learning process and to implement the gamification concept.

5.2.1 Main menu

From the Main menu, the trainee can access everything associated with his training. An example of a possible structure of the main menu can be seen in figure 5.1. In the sub menu settings, the trainee can change parameters to adapt to individual preferences. The trainee can choose what kind of feedback he wants during training, i.e. visual, audial or kinesthetic. Key mappings on the controllers can be personalised to suit the individual. Audio settings include parameter such as volume control for notifications, sound and voice over.

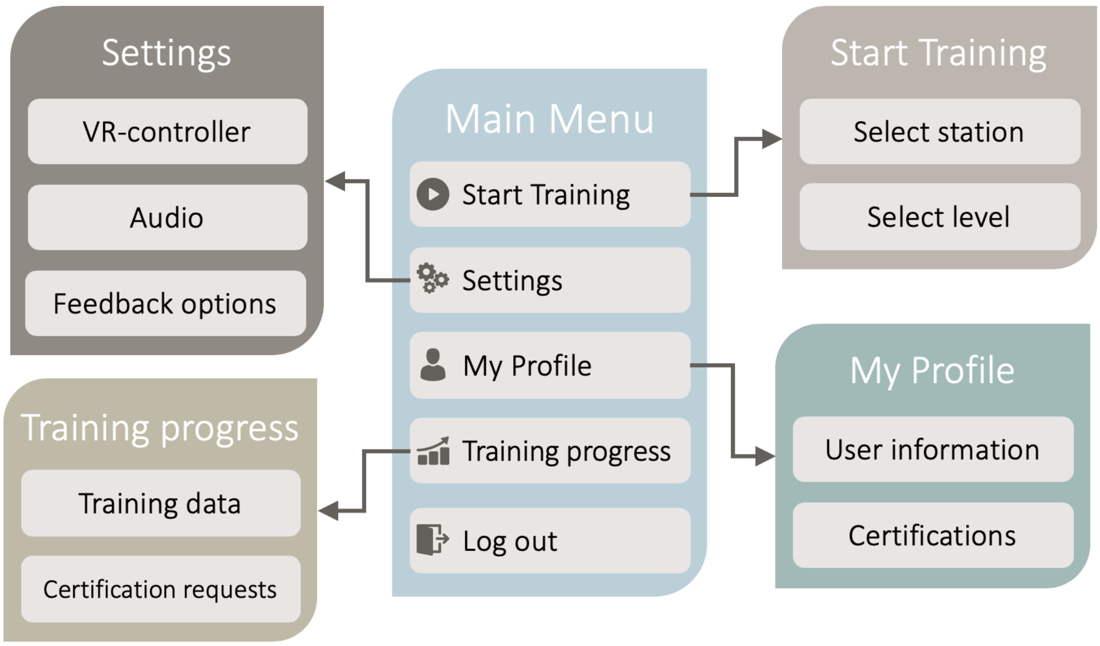


Figure 5.1: Proposal for the design of the main menu

The trainee can track his progress and access detailed information about completed training sessions. The information is categorised according to, for example, ergonomics, assembly sequence, standardised work and quality. The trainee can evaluate their progress and compare it to the learning outcomes. The data is easily accessible and presented in an intuitive way to the trainee.

In the Start Training menu, the trainee access all stations available to practice at. The trainee selects which station he wants to start at and at which level, depending on previous accomplished levels. It is never possible for the trainee to skip a level since these buttons will be looked until the previous level is completed. This is shown in figure 5.2.

My profile is where all information about the trainee is stored. The profile is created in the create account block earlier described in section 5.3. The sub menu also shows certifications taken by the trainee, i.e. where he is allowed to work at the production line.

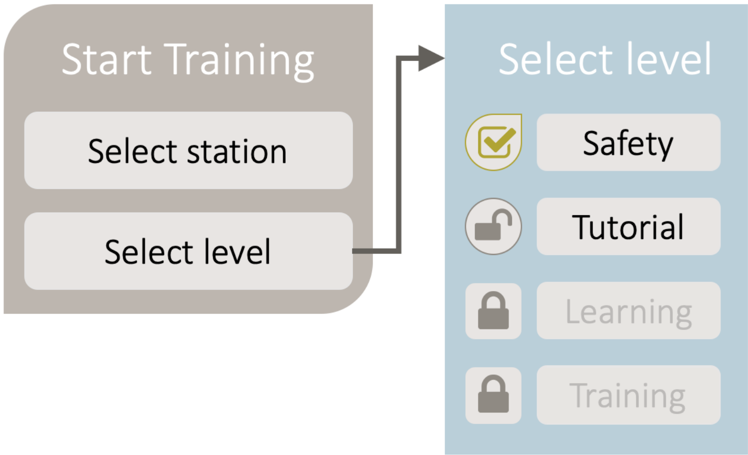


Figure 5.2: Visualisation of the selection of training level

5.2.2 Progress bar

During the training session, a progress bar allows the trainee to track his own performance in real time. A possible design of the progress bar is shown in figure 5.3. The progress bar shows the ongoing time, which tasks have been accomplished in the assembly and all logged errors caused by the trainee.

Figure 5.3: Design of the progress bar

5.2.3 Help bar

The trainee can access a help bar whenever he encounters a problem, see figure 5.4. The help bar includes support with the VR technology, e.g. how to use the controllers, and help with the assembly such as requesting more information to be able to accomplish a task.

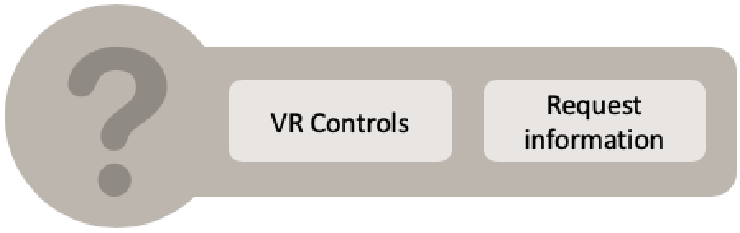


Figure 5.4: Design of the help bar

5.2.4 Present results

After each training session, the result will be presented to the trainee. An example of a possible interface of the results is visualised in figure 5.5.

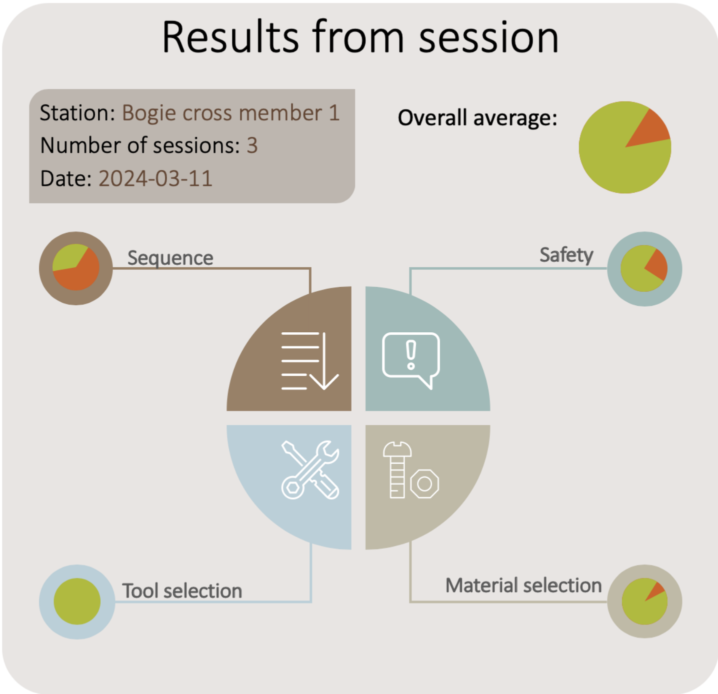


Figure 5.5: Present results from training session

The results are categorised into groups such as assemble in the right sequence, choosing the correct tool, awareness of safety aspects and mounting the right material. The sequence parts refer to the trainee assembling the product according to the sequence stated in the SOPs and sequence sheets. Safety bases its result on whether the trainee has used the tools in the correct safe way or used ergonomic help tools whenever available. Tool selections reveal however the trainee is aware of in which situation each tool is to be used. Finally, material selection refers to picking and mounting the right material to the product. A logged error in this category could for example be that the trainee has assembled screws with wrong screw length. The trainee can access the result from previous training sessions through the main menu previously described in section 5.2.1.

5.3 Main flow

The main flow is constructed based on a few prerequisites for the trainee. The trainee is expected to complete the introductory training at the training facility prior to the start of the virtual training. When arriving at a department the trainee is assigned to a specific station. He is given a tour of the department to get familiarised with the environment, similar to the current procedure described in section 4.3.2.

The main flow, see figure 5.6, starts off by letting the trainee choose whether they are a new operator or not. New operators need to create an account and continue through an introduction to VR training. Operators that have previously trained within the system are directly transferred to login and the main menu. From the main menu, the trainee is able to choose the level to train at the specific moment. Everything in the flow up to the choice of level is desktop based. VR glasses are put on when the trainee enters a certain level. The main flows constituting blocks are listed below and described in the following paragraphs:

- Create Account
- Introduction to VR training
- Login
- Main Menu

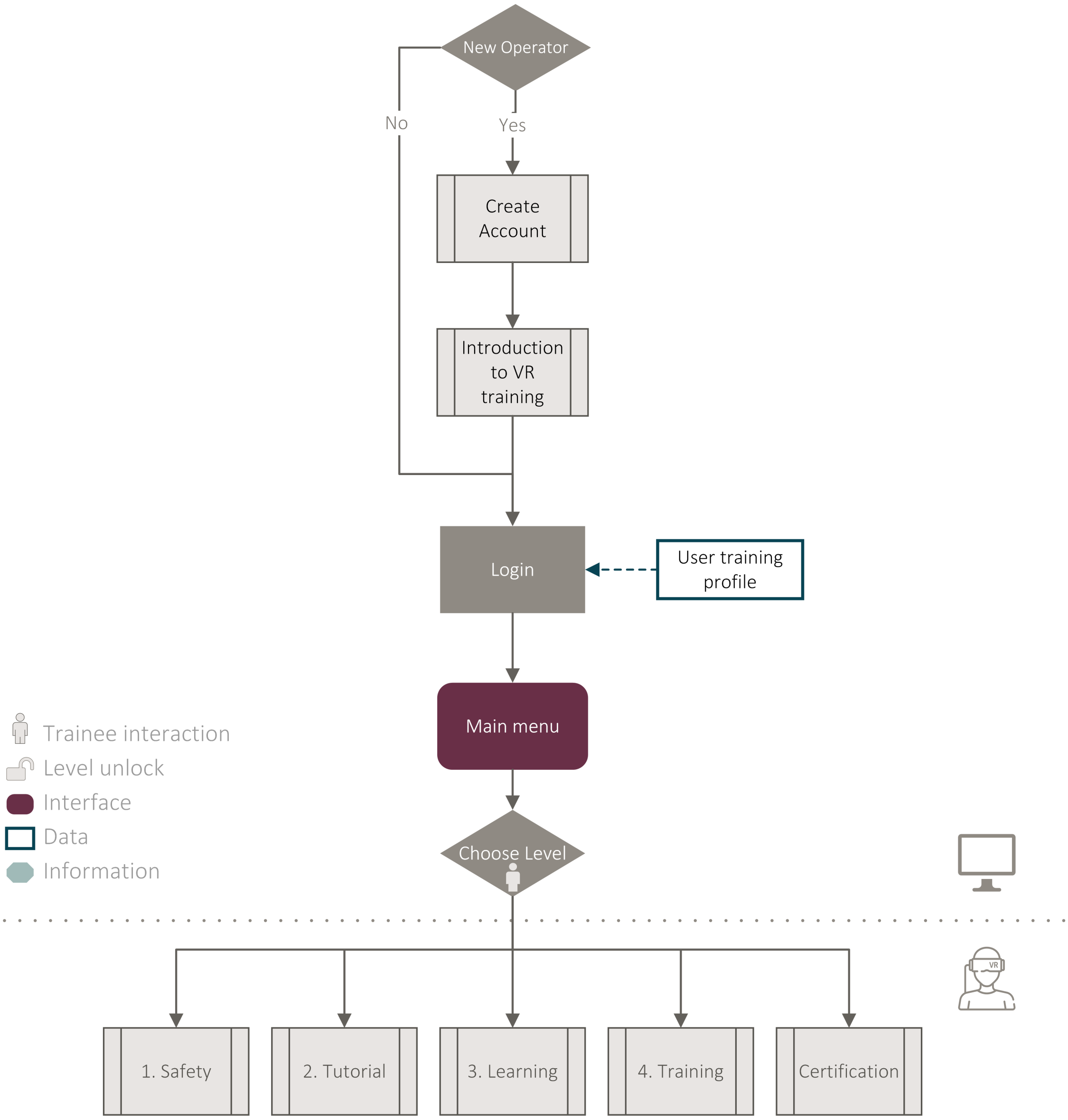


Figure 5.6: Main flow

Create Account

New trainees that have not used the virtual training system starts by creating an account. The account consists of a profile that is connected to an overall system. The idea is that the profile is connected to other applications within the organisation through an overall system. This system is preferably an HR-system used to store employee data. The system can include a competency matrix, career platform and a career path. The competence matrix contains information about certifications, completed training and other expertise the employee has. The matrix can be used by the employees themselves or by a production leader to allocate workers according to their knowledge. The career path and career platform are used to track the development of employees and present available options to advance further. All this information is connected to the personal profile connected to each employee and available as a resource for multiple applications within the organisation.

When creating an account for virtual training, additional information is added to this profile. This information is used to individualise the training and adapt it to the trainee. Multiple choices are available such as preferred language, preferred information media, i.e. text or pictures. These settings are used to generate personalised instructions.

Introduction to VR training

The purpose of the introduction to VR training is to explain how to use the equipment and the training procedure. The exact subflow is not defined in this thesis. However, the subflow will contain information about how the equipment is used. Examples could be how the VR-glasses should be put on and how the controllers are used.

Login

The trainee logs into the system using the credentials created in section 5.3.

5.3.1 Training Levels

The workflow is based on four levels of training: Safety, Tutorial, Learning and Training. The levels are influenced by the job instruction 4-step method earlier described in 2.6.1. The four levels are based on a locked approval system. The safety track is compulsory at every station and must be approved before being able to enter the tutorial level. Each level unlocks the next and makes it visible in the main menu. However, it is always possible to go back to previous levels.

Multiple blocks are common for the different training levels, these are described in the paragraphs below. In the later descriptions of each training level these blocks are marked with an asterisk (*) in the list of constituting blocks.

Score

The required score to pass a level is not formally set in this thesis. However, as safety is the most important track of all, it is required to fulfil 100 % score to unlock the next level.

Present learning outcomes

The learning outcomes for the station is presented to ensure that the trainee is aware of what is expected to know after the training session. The learning outcomes are based on the SOP documents which includes factors such as assembly sequence, quality aspects and ergonomic work.

5.3.1.1 Safety level

The purpose of the safety level is to notify the trainee about the safety and ergonomic risks that appear at the station. The flow for the safety level is shown in figure 5.7. The trainee is informed about the critical tasks including safety risks and is able to try the tasks on its own. Results from the tryout are presented and, depending on the score, the trainee passes or have to redo the tasks.

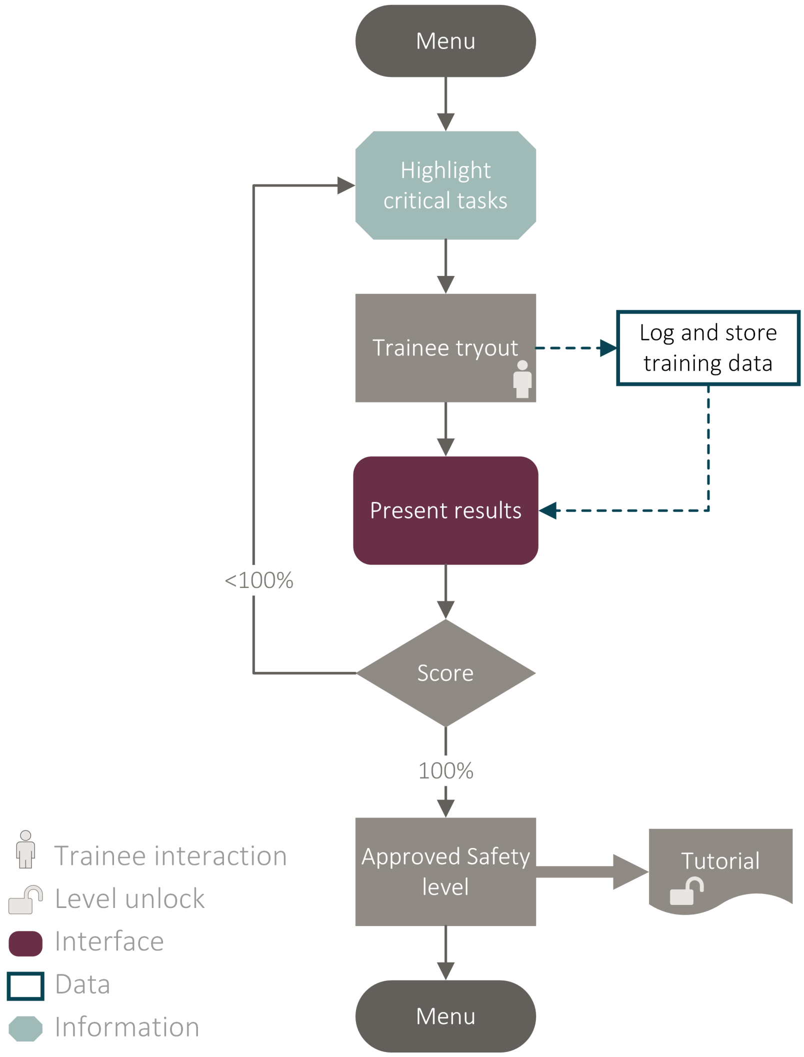


Figure 5.7: Safety flow

The blocks constituting the safety track are listed below:

- Highlight critical tasks
- Trainee tryout
- Present Results*
- Score*

All blocks are separately described and explained in the following paragraphs.

Highlight critical tasks

The system highlights and visualises all tasks in the assembly which include possible risks and explain them to the trainee in terms of what the risk is, why it is a risk and how it can be prevented. Examples of critical task can be a case where a lifting tool is supposed to be used, due to ergonomic factors, or the use of a tool that can cause injury if not handled the correct way.

Trainee tryout

At this stage, the trainee gets the chance to interact by trying himself, i.e. holding a tool in the correct way. The system is giving instant feedback about the body position of the trainee and notifies risks.

5.3.1.2 Tutorial level

The Tutorial level focuses on introducing the trainee to the assembly. The flow for the tutorial level is shown in figure 5.8. The system presents the learning outcomes for the station, explaining clearly what is expected from the trainee to pass the level. A demonstration of the whole assembly follows and follow up questions are asked to the trainee. Questions are asked to keep the trainee engaged throughout the demonstration and the answers are logged and stored for later evaluation. The results from the follow up questions are presented and, depending on the score, unlocks the next level or forces repetition.

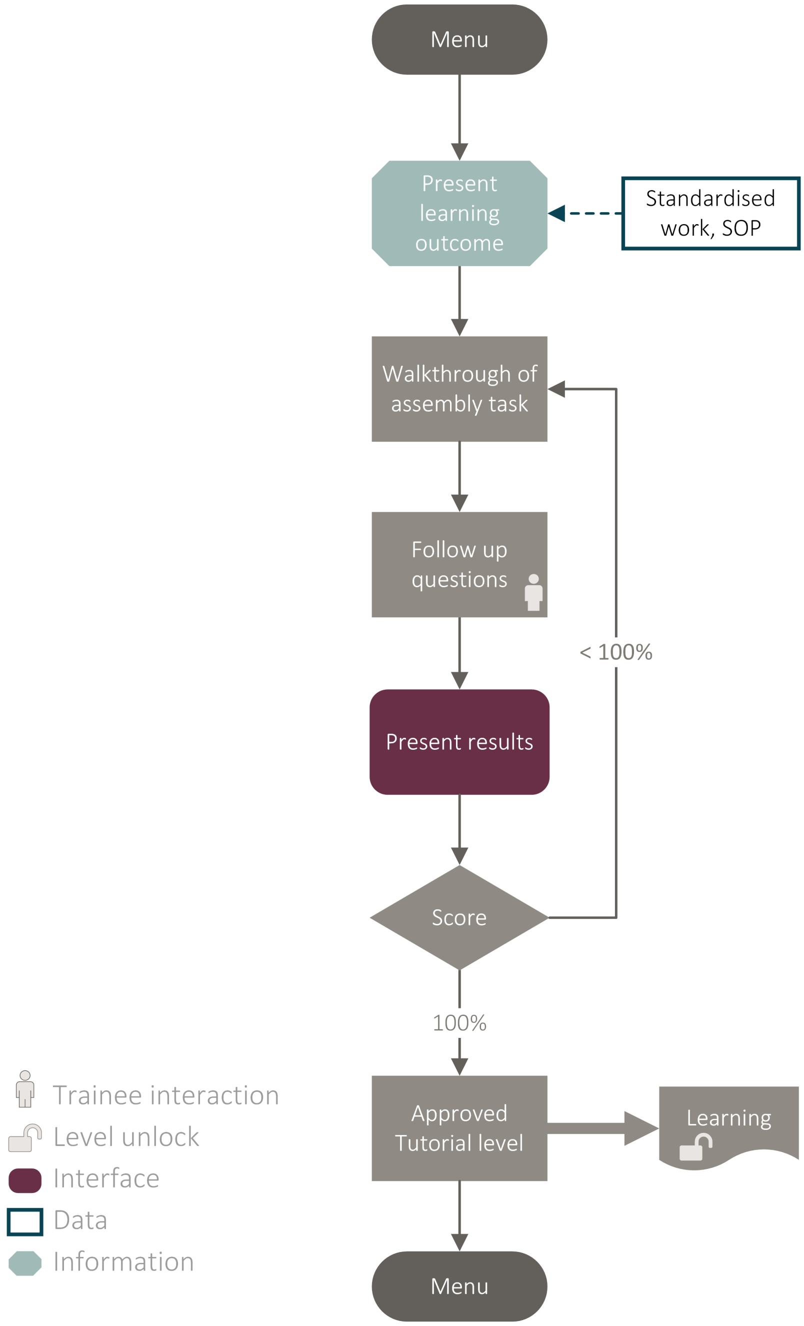


Figure 5.8: Tutorial flow

All blocks constituting the tutorial level are listed and further described in the paragraphs below:

- Present learning outcomes*
- Walkthrough of assembly task
- Follow up questions

- Present results*
- Score*

Walkthrough of assembly task

The trainee is at this stage observing a simulation of the assembly through the eyes of an operator. Every task is explained and critical operations emphasised. The trainee can pause the simulation to zoom in on the product or change viewing angle. The simulation can also be replayed if the trainee is unsure of the procedure of any sequence.

Follow up questions

Questions will be asked to the trainee during the whole demonstration of the assembly. Examples of questions could be to answer which tool was used at a specific sequence or what screw length is used at some part. All questions will be formed in how, what and why statements to create an understanding of the work and procedures.

5.3.1.3 Learning level

At the learning level, the trainee starts to interact more. The flow for the learning level is shown in figure 5.9. The assembly is carried out by the trainee with support such as the choice to request more information and asking for help in an instruction. The trainee gets instant feedback when doing something wrong and receives an explanation of what, how and why the error occurred.

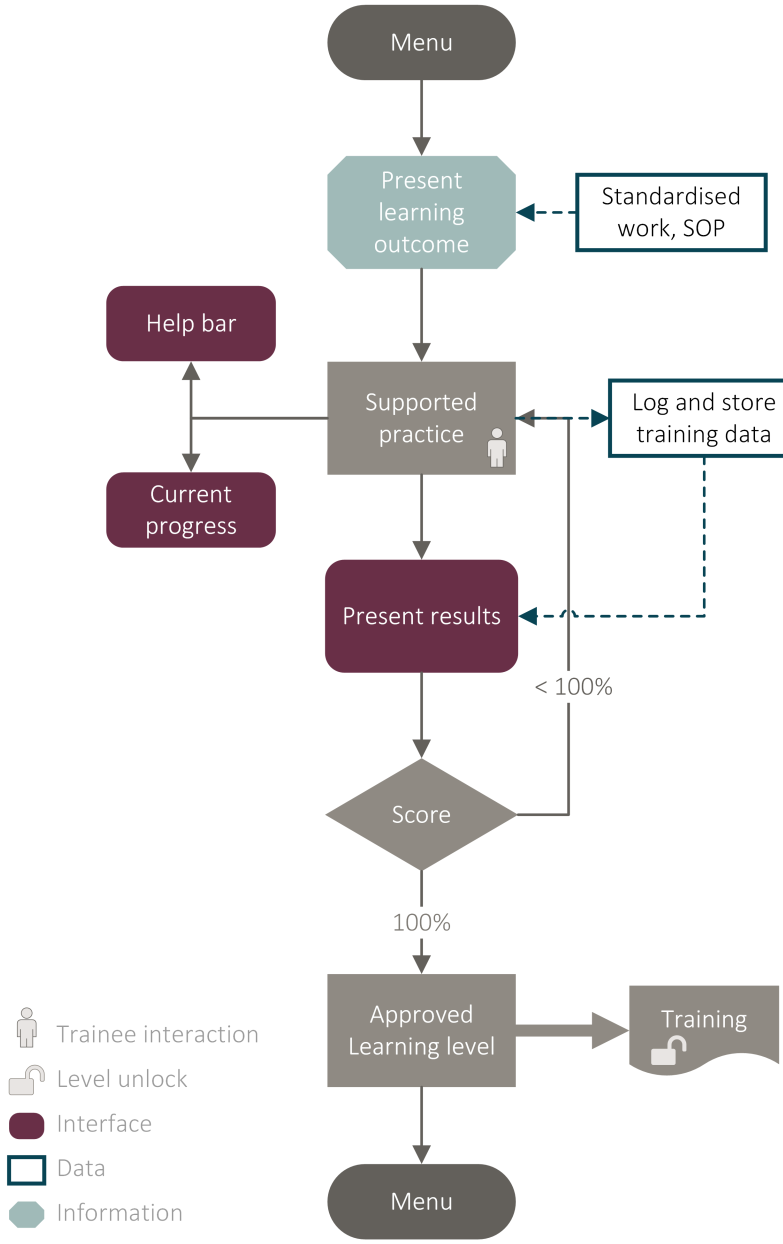


Figure 5.9: Learning flow

All blocks constituting the learning level are listed and further described in the paragraphs below:

- Present learning outcome*
- Supported practice
- Present Results*
- Score*

Supported practice

The trainee is now starting to practice the assembly on his own with support from the help bar. The trainee can at any time request more information and instructions, from the help bar, to be able to finish each sequence. Errors caused by the trainee, such as wrong placement or incorrect choice of tool to use, are instantly feedbacked by the system. The system explains what kind of error has occurred, why it is an error and how it can be prevented in the future.

5.3.1.4 Training level

The training level is the final level and strives to be as close to reality as possible to prepare the trainee for the real assembly line. The flow for the training level is shown in figure 5.10. The trainee practice the tasks with no more information and instructions that are available in reality. All error logging and feedback are presented at the end of the assembly.

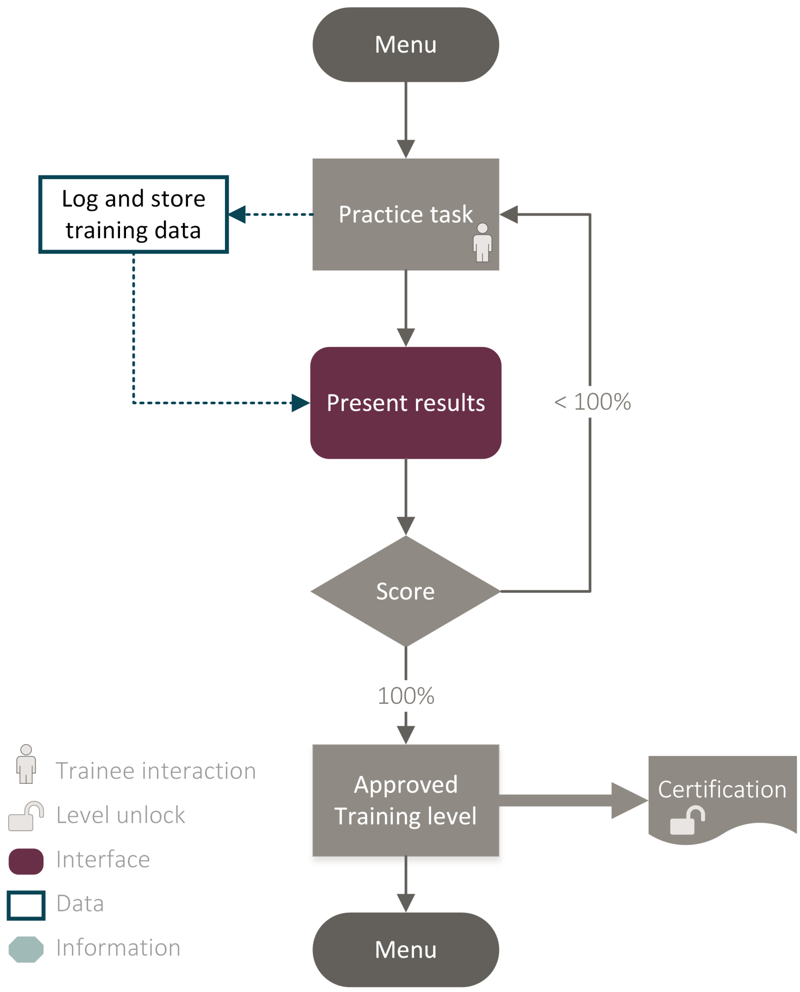


Figure 5.10: Training flow

All blocks constituting the training level are listed and further described in the paragraphs below:

- Practice task
- Present results*
- Score*

Practice task

The trainee practices the tasks in the whole assembly with no additional help other than the SOP and SPRINT documents. The trainee is no longer able to be given extra help or request more information in any sequence of the assembly. The system will track all errors caused by the trainee and log them to later presentation of result and there will be no instant feedback to the trainee. The scenario will be as close as possible to reality to prepare the trainee to the real production line.

5.3.1.5 Certification

The trainee can request certification after the training level is completed. During the certification, a team leader or production leader is present to review the performance of the trainee. Data from the training level is used as a foundation for the work performance aspect of the certification. The details of the certifications process are not fully developed. However, after the certification in the virtual environment, the trainee is not ready to work unsupervised at the production line. Additional experience is required and a second certification in the real environment is required before the trainee is allowed to work unsupervised.

6 Discussion

This chapter discusses the findings in relation to the theoretical framework. The chapter starts with a discussion of the preliminary study including the findings in the literature study and comments on the current training. Secondly, the workflow is explained and choices discussed. Suggestions are made regarding the implementation of the workflow.

6.1 Current research and production

This section comment on the major findings from the literature study and discusses issues related to the current training.

Literature study

The result from the literature study demonstrated both possibilities and limitations with virtual training using VR. These aspects were considered when developing the workflow. There is a general opinion among researchers that the design of VR applications lack defined learning theories as they focus more on the technical aspects. The focus of this thesis has been to develop a workflow supported by established learning theories.

Findings from the literature conclude that virtual training cannot completely substitute traditional training of operators. The characteristics of manual assembly are skill based work which is hard to learn without hands on experience. These findings are to a high degree based on studies conducted in a laboratory setting with simple assembly tasks not representing the complex environment of a real industrial setting. Virtual training can be implemented using various technologies and a common choice is a desktop based system. The authors believed that using virtual reality would support the learning in a better way than a desktop based system can. Though it became obvious that virtual training using VR still cannot replace traditional training. The authors believe that it could reduce the time needed for traditional training further than a desktop based system can.

Use case at Volvo GTO

The presented results are based on a specific part of the production at the Tuve plant as described in section 4.2. The selected case has most likely affected the result in a number of ways. Some key factors that have been identified will be discussed in this section.

The first aspect that affects the result is the chosen product that is assembled, for this case it is the bogie cross member. The complexity of the product in combination with the number of variants has probably set the requirements for training. The part of the bogie cross member assembly that is the most complex is the cable harness. Due to the high complexity and variability, this assembly task was not considered when developing the workflow. This will probably delimit the effectiveness of the training process if the workflow is implemented for the cable harness stations. The same limitations could possibly occur for other assembly tasks that were not considered in the case. These limitations will be obvious in the implementation stage of virtual training. It is evident that some processes are hard to simulate in a virtual environment, the cable harness is one obvious example. This problem needs to be further evaluated during the implementation to understand what is feasible. It seems that high complexity is a obstacle that reduces the learning possibilities with virtual training. Complexity does, in this case, refer to assembly tasks requiring a high degree of skill and craftsmanship to complete. Therefore it is suggested to focus virtual training on knowledge rather than skill. When implementing the workflow this should be considered for the chosen assembly station and product.

Current training

There is an established procedure for training new operators within the organisation today. All new operators get the same introduction to ensure that they have the same prerequisites. This part of the training was not considered a part of the virtual training. However, it is important to identify the prior knowledge possessed by the trainee in order to set the level for the virtual training. The content of the introductory training appears sufficient to support virtual training. It is possible to include parts of the introductory training in the virtual training, such as safety and company knowledge, i.e. the more theoretical aspects. The hands on experiences are not possible to replicate in a virtual environment using the current technology.

The major concern connected to the introductory training is the waiting time until the trainee is employed and assigned to a department. It could take several weeks until the trainee is employed. Therefore parts of the training might be forgotten when starting at the assigned department. This is supported by the forgetting curve explained in section 2.4.5. The forgetting curve illustrates that repetition is essential to sustain knowledge. It might be necessary to include some sort of repetition just before the virtual training or include it in the content of the virtual training. However, the source of the problem is more organisational than training related and the best solution would be to shorten the time between the introductory training and the virtual training.

There is a standardised process for training at a department established through a certification document. The process is similar to the 4-Step JI method described in section 2.6.1 which is common in the industry. The trainee is assigned a supervisor who, by following the steps towards certification, teaches the trainee all necessary knowledge. However, the interviews conducted showed that the process still varies between supervisors and the specific training sessions. The training outcome and quality is, therefore, most likely not consistent. One reason for this is the content of the certification document. The process is highly dependent on the evaluation performed by the supervisor and is therefore different for each individual. This problem should not occur using the developed workflow since it is not based on subjective evaluation. Instead, every trainee is evaluated consistently by the system. It is also a possibility that the supervisor forgets to explain certain aspects, this is also prevented by using virtual training.

The biggest reason for the inconsistent training identified is the production environment itself. Every training experience will be unique since every day at the production line is unique. The mix of product variants changes which affect the training scene. Employee turnover will set the training time frame, understaffing leads to shorter training periods since the supervisor is needed as an operator as well. These are problems that were considered when developing the workflow. Virtual training might reduce some of these problems if implemented in the right way. For example, the product variety could be easily specified in a virtual environment. This allows the trainee to learn one variant at a time to ease the cognitive load. Rare variants can also be chosen instead of relying on them to appear on the line within the training period as of today. The problem with employee turnover and training time is harder to address. Ideally, there should be a set training time sufficient to the specific station. However, there are no specified times in the developed workflow. The current training process is adapted to meet the individuals needs and therefore the duration is not defined. The same idea is applied to the workflow for virtual training. The focus is on learning outcomes and not to shorten the training period.

6.2 Explanation of the workflow

The focus behind the development of the workflow is to create a supportive cognitive learning environment. This means taking into consideration several factors such as problem-solving skills, memory retention, perception of learned material and thinking skills. A lot of the constructed blocks and scenarios are permeated by the constructivism theory, described previously in section 2.4.1.1. All training levels involves some degree of a learning-by-doing process by combining the trainee's knowledge with inputs from his senses. The trainee is both mentally and physically involved in the training since he must be able to read instructions, solve problems and physically assemble the product. This approach creates a learner-centred process instead of focusing on the trainer. A trainer should, however, be available to support whenever the trainee needs help.

Interface

The interfaces presented in the thesis are only conceptual and aim to help the reader understand the desired requirements. All interfaces are designed to involve the gamification aspect to increase motivation among the trainees. The progress bar allows the trainee to be active in his training, following logged errors, mistakes and achievements in real time. Visually given rewards during the training session increases the extrinsic motivation of the trainee. In the results interface, the trainee can track his achievements and previous results. He can go back and repeat training sessions whenever wanted to achieve a higher score and increase learning. It is important to design the training in a way that gives the trainee autonomy e.g. sense of control in the training as this will function as an intrinsic reward. The different kind of interfaces available in the training is therefore of high importance.

Training levels

The training levels of the workflow is influenced by the 4 step JI-method previously explained in section 2.6.1. The method covers numerous aspects of human nature that influence the effect on learning, such as automic learning, the forgetfulness curve and short and long-term memory.

The three training levels developed can be connected to the learning modes described in section 2.4.4. Initially, the trainee starts in the learning mode where he learns new tasks. This mode can also be connected to the cognitive stage in the learning curve, see section 2.4.3. When the trainee practices the tutorial level, he is watching the whole assembly and tries to comprehend the tasks and what they request. As the training progress, the trainee moves towards the operational mode as seen in figure 6.1.

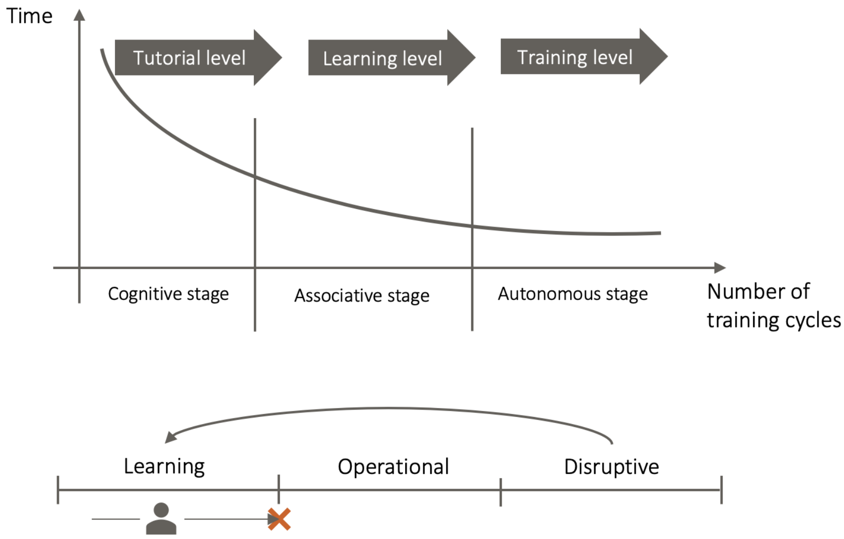


Figure 6.1: Illustration of the connection between the learning modes, learning curve and the training levels

A difference might appear when the trainee starts the learning level in the training. He is still in the learning mode but may advance to the associative stage in the learning curve. In the learning level of the training, the trainee converts his initial understanding to practical acting as he starts performing the assembly. The trainee will most likely not head into the operational mode in the virtual training but always moving towards it. However, the trainee can in the training level move into the autonomous stage in the learning curve. In the autonomous stage, tasks can be performed with less processing, meaning that other perceptual or cognitive actions can take place as well.

As earlier stated, the trainee might never end up in the operational mode. The boundary between the learning and the operational mode marked as a cross in figure 6.1 is when the trainee is most likely ready for certification. Even though the trainee will not be at the operational level, he will most certainly end up in the disruptive level. New tasks and procedures that are unknown for the operator will appear occasionally during the training sessions. In these cases, the trainee will move into the learning mode again, trying to comprehend and grasp new knowledge. The occurrence of this scenario is further described in section 6.2.

Main flow

The processes in the main flow are conducted in a desktop environment. The only exception might be the introduction to VR training. This subprocess is not described in detail but will probably contain some sort of session where the trainee can get familiar with the VR technology. The desktop environment is chosen since it is not necessary to do the required tasks in an immersive environment. It is likely easier to create an account and navigate a menu in an environment that most users have experience from. This will probably make the system less intimidating to new users which makes them feel confident.

Creating an account for the virtual training will add information to a profile in an overall HR-system. This system is not defined but is a future ambition within the organisation. It is suggested that the system for virtual training is integrated into such an HR-system. A centralised system for data management regarding operators will ensure that information is up to date and accessible by the right people.

Safety

The safety level is essential in order to prevent injuries. There are assembly tasks that include ergonomic risks or heavy tools that could cause injuries if used in the wrong way. This training level allows the trainee to get introduced to these aspects in a safe environment. The virtual training sessions enable scenarios that are not safe to reenact in the real world. Such as demonstrating what happens if you use a tool the wrong way. This could increase the understanding of risks and maintain safe working procedures. It appears that a current problem is that operators forget to do tasks in the intended way, rather they do it as it best suits themselves. This might imply unergonomic or unsafe behaviour. One example that is common is not using the lifting tool for installation of heavier parts. Even though the operator manages the task without the tool, in the long run, ergonomic problems might occur. If these risks are explained during the training, it is more likely that the trainee will remember to use the tool.

The trainee gets to try different tasks himself to further support the learning. This is supported by the constructivism view of learning by interaction described in section 2.4.1.1. During the session data is collected, such as posture and position of the trainee. The trainee performs a task and is informed how to do it in a standardised way.

After the tasks are complete the results based on the collected data are presented in order to address any mistakes or risks. The posture is used to analyse the ergonomic risks and to inform the trainee on how he can position himself to reduce the risks. The body position can be used for several aspects, for example, how the hands are positioned on a tool or where the trainee is located when doing the task. This data can be used to identify possible risks and present them to the trainee with an explanation on how to avoid them.

The trainee is evaluated and receives a score. This process is not defined but it is necessary to achieve the highest score to be approved. When the trainee receives a lower score a new session is started which is adapted to the results from previous ones. If every task needs to be repeated frustration might be a problem and the trainee becomes unmotivated.

Tutorial

The tutorial level is based on the knowledge components presented by Gorecky et al. [41] described in section 4.1.3. They consist of object, local context, instrumental context, conditional context and consecutive context. These aspects are considered when developing each scenario for every station. First, every part is explained, what it looks like and if there are any variants i.e. the object component. The idea is that the trainee will recognise every part and know its location in the production environment. Procedures regarding what to do if material is missing or have quality issues are also introduced. The next step is to show where the part is located on the assembled product, this is the local context. To aid the understanding the part will be visualised on several completion levels: the part mounted on the product as it is on the specific station; how it looks when the subassembly is completed; how the finished truck looks like and where the part is located. These different levels will likely support the understanding of each part and its purpose. It appears that it is hard to contextualise every part when only seeing it in a small section of the production line. Quality might increase when operators know how their part is related to the rest of the assembly.

The next step is to introduce what tools are used for the different parts, this is the instrumental context. The tools are demonstrated for the trainee and every functionality is explained. Safety risks are briefly repeated from the previous level to contextualise and maintain the knowledge. If there are any specific conditions that affect the task they are emphasised in the conditional context component. The last step is to present the assembly sequence, this is the consecutive context. The sequence is explained to ensure that the trainee understands the purpose. Sometimes a task might be performed in an unintuitive way and then it is important to make sure that the trainee notices why. If the trainee understands the reason he is more likely to remember.

Every task is concluded by follow up questions related to the knowledge components. The questions are a way to make sure that the trainee is engaged during the walkthrough of each task. They are also a way to emphasise especially critical tasks or tasks with quality issues. It is suggested that the questions are presented in the virtual environment to enable visual support and interaction. For example, a question could be: "What tool is used when fastening the console?". Then the console could be highlighted on the assembly and the trainee answers the question by grasping the correct tool. This will create an interactive experience that increases learning outcomes.

The results from the questions are presented to the trainee in order to illustrate the progress. The results show what questions were answered incorrectly and in which categories they belong to. The categories could be organised according to the knowledge components discussed earlier. When all tasks are completed a final score is given. If the score is too low, the walkthrough is repeated focusing on the areas that need improvements.

Learning

The trainee performs each task in the correct sequence at the learning level. The session starts with a presentation of the learning outcome to once again emphasise on the important aspects. The forgetting curve presented in section 2.4.5 illustrates the importance of repetition to support knowledge retention. The trainee performs each task, the same instructions as in the real production environment are available. If the trainee is unsure of the next step he can request additional instructions through the help bar. The idea is to limit the amount of instructions presented and instead let the trainee request them when needed. This will most likely enable the trainee to reflect on the tasks performed. If the trainee instead received step by step instructions explaining each task in detail he might become bored and just follow the instructions without thinking. To further aid the learning process instant feedback is presented if any errors occur. The idea is to explain what went wrong, how it affects the product and how to avoid it. The errors are also logged and stored to be presented after the session is completed. Another option that is considered, but disregarded, is to fully prevent the trainee from doing mistakes, i.e. it is not possible to pick the wrong part or tool. But it is assumed that this approach is less beneficial in the learning process. It might decrease the trainee engagement resulting in randomly trying to pick a part until the correct one is chosen. Instead, by receiving feedback the trainee is encouraged to choose the correct part.

The aim of the learning level is for the trainee to become confident in performing every task independently. The learning session should be individually adapted to fit the need of the trainee and thus increase the learning outcomes. When training on a complex product, additional information should be available to prevent cognitive overload according to Hoedth et al. [44]. This information is requested and individualised according to the preference of the trainee. The information could be text, pictures, markers in the virtual environment or voice over. Compared to the instructions, the additional information is not available in a real world scenario, thus the possibilities with VR technology are utilised.

Training

The goal of the training level is to design it to be as close as possible to reality. It is highly difficult to simulate a virtual environment to become the same as the real world. However, there are aspects that are possible in the virtual world that are not possible to practice in the real world. One big advantage of using VR is the ability to simulate certain scenarios. VR can in the training level be used to simulate events that would possibly put an operator in a disruptive mode. An event could for example be to simulate lack of components, machine failure or other disturbances and teach the trainee what to do when these problems occur. It is also possible to apply audio disturbances which challenge the trainee to carry on the assembly during these conditions. The real production line is not an isolated place like the one in the virtual world. To close the gap as much as possible between the virtual and real world, disturbances like these are desirable and will prepare the trainee for unexpected events in the real production.

Certification

Certification is a subflow of the main flow that has not been further developed in this thesis. The reason for this is the strong belief that certification cannot be made solely in the VR training. An idea is that once the training level has been accomplished, the certification is triggered. This could mean that a message appears in the profile of the trainee, stating that he is ready for certification of the station. The team leader or production leader would then see which trainees are ready to be tested on the station for a certification. There are requirements in the certification document that can not be tested in the virtual world. It is strongly believed that human contact is necessary to ensure that the trainee has learned the station before he is certified and allowed to work unsupervised at the production line. The trainee still needs to spend time at the real production with the observation from a team leader. However, with an accomplished virtual training at the station, the risk for high cognitive load and stress is decreased since the trainee is already familiarised with the environment and material. This may also result in a shorter training period at the real production line.

6.3 Prerequisites for a successful implementation

There are various aspects to consider for the future implementation of the workflow. Table 6.1 shows a selection of categories and questions that can be used when implementing a VR learning system.

Table 6.1: List of requirements to consider when implementing a VR training system

Categories	Check list
Immersion	-Is the training experience immersive?
	-Does the system use multi-sensory outputs?
Interactivity	-What kind of inputs are used? (Positional tracking, handmotions etc.)
	-Is the environment interactive?
Duration	-What is the duration of a training session?
Simulation	-Does the system prepare the trainee for a real world scenario?
	-Does the environment allow for problem solving scenarios?
Creativity and imagination	-Does the system make use of the benefits with VR, e.g. offer experiences that can not be experiences in the real world?
Personalisation	-Is the training adapted to the user?
Feedback and rewards	-How is feedback presented to the trainee?
	-How is the progress of the trainee presented?
Feasibility	-Is the system dependent on a specific technology?
Learning content	-What does the trainee learn from the system?
	-How does the system communicate to the trainee? e.g. Text, audio or kinesthetics etc.
	-How is learning content integrated in the experience?
Embedding in educational practice	-Where should the training be performed? e.g. Office, production area etc.
	-Is a teacher involved in the training? If so, what is his role?
	-How flexible is the training location?

Some aspects are identified as especially important in the creation of a learning environment and are further discussed in the following paragraphs. However, all aspects should be regarded in the process of an implementation.

Organising virtual training

A big part of implementing a virtual training system is to decide how it should be practically organised. This is something that has not been evaluated in this thesis. To implement any kind of system into an organisation requires several questions to be answered. In this case, who should be responsible for the training? What kind of facility should be used and where? Who should be the trainer? Which part of the organisation should be responsible for the investment? These are only a few questions to be answered regarding the organisational part of the training system. It is an important aspect to bear in mind, even though it has been limited from this thesis.

Technology influence on VR training

Implementing a training system requires hardware in several categories. This is not something that has been investigated in this thesis, however, some conceptual ideas are presented in this section.

There are various technologies for interacting with the virtual environment. One method is to use a handheld control device, for example, the ones shown in figure 2.1. They provide a fixed set of buttons and functionality. Another option is using a set of gloves to interact with the virtual environment. The gloves allow the user to see his own hands in the virtual environment. The user can move his fingers and the gloves track the movement and replicate it with a virtual hand. This type of interaction will likely increase the immersiveness and realism. The user could, for example, pick and place objects by grasping them with their hand rather than pointing at them with a controller and pressing a button. This is also more effective since the sense of scale and distance increases when the user can see his own hands and thereby use them as a reference. Two of the researcher interviewed expressed that it is much harder to pick objects using a controller especially when the object is small.

To further increase the realism, parts and tools could be 3D-printed. These should be tracked by the VR system so that they control the movement of the virtual counterpart. To successfully use this idea the gloves are a necessity.

Ergonomics are a vital part of manual assembly. The training process should address ergonomic risks and how they are avoided. By monitoring the trainee during the training session real-time ergonomic analyses could be performed. The system could then intervene when an ergonomic risk occurs and explain what the risk is and how it is avoided. This kind of system ensures that the correct working procedures are learned. The specification of the system is not elaborated in this thesis. However, there are some ideas regarding implementation. Initially a rather simple solution requiring no additional equipment is to use the controllers to estimate the position of the user. This method is most likely not satisfactory to achieve useful ergonomic data. Another option is to let the user wear a suite with a pattern that a camera can track. By analysing the image a computer could then define the posture of the user and perform an ergonomic evaluation in real time.

Usability

When implementing the workflow and developing the virtual environment it is important to consider usability. Virtual reality is a rather new technology that few people have experience from. The training system should be adapted to the users and be as intuitive to use as possible. Users will have various backgrounds and experience with technology. However, the system should not be an obstacle to the training process. To make sure every user knows how to use the system the introduction to VR training in the main flow is essential. The introduction is presented in figure 5.6 as a subflow that is not further visualised. It is preferable that the introduction includes a scenario where the trainee gets familiarised with the equipment used in training. The trainee should be comfortable using the training equipment before starting a training session. Otherwise, too much focus might be needed to use the controls and negatively affect the learning.

Another aspect of usability is the possibility to individualise the training. The trainee can adapt the training experience to personal preference to increase usability. The controls should be possible to change according to what is best suitable for the individual, e.g. if the trainee is left or right handed. During training, information can be presented to the trainee by voice-over or text messages. Usability would increase if these could be customised in terms of language, how much information is presented and the distribution of text and audio.

User acceptance

Introducing new technology or work methods can sometimes be met with scepticism or rejection by the intended users. This might result in a new system that is not used, or used in another way than intended. To avoid these problems it is important to engage the users in the development phase. Therefore it is beneficial to include employees from the production plant such as team leaders and operators for the next stage of developing virtual training. The literature study showed that interaction design is also a factor that affects user acceptance.

Cybersickness

A problem related to the use of virtual reality is cybersickness that affects some of the users, resulting in nausea and headache [53]. Cybersickness is a complex issue that is hard to prevent. This problem is important to consider when implementing a VR system for training. It is not recommended to use the HMD for a period longer than one hour. This is based on discussions with researchers within Volvo GTO that has experience working with VR systems. More tests are required to investigate how cybersickness occur and for how long a training session could last.

6.4 Virtual training opportunities

The developed workflow has multiple benefits that the current training process described in section 4.3.2 does not provide. The operator does not have the opportunity to repeat the training continuously to retain the knowledge, therefore much of it may be forgotten. The speed of forgetting is described by the forgetting curve introduced in section 2.4.5. The obtained information is lost when no repetition to retain it exists. A good training strategy must simply counter the forgetting effect. The developed workflow in this thesis enables the operator to go back and repeat several of the training levels after he is certified and works in production. To ensure highly skilled operators a mandatory monthly repetition session could be established. Since the virtual training does not rely on the production line to be running the repetition sessions can be scheduled on days with planned production stops. Recurrent repetition will increasingly limit the forgetting and maintain the standardised work.

Highly skilled operators are important to achieve a sustainable production system. Virtual training can likely decrease the cognitive load experienced by the operators during training. This will improve working conditions and thereby contribute to a more socially sustainable workplace. Skilled operators tend to make fewer errors resulting in quality problems or rework. This improvement will affect both the economic and environmental parts of sustainability. Reduced scrap will decrease the amount of material needed which benefits the environment as well as lower the expenses.

The developed model is inherently flexible and is not dependent on specific hardware or environment. Therefore it can be implemented for different use cases. The hardware used is currently an HMD display for virtual reality, the workflow allows for this hardware to change as new technology is constantly being developed.

6.5 Quality of research

The main foundation of the results in this thesis is interviews and literature study. One of the major contributing factors influencing the direction of the research is the choice of interviewees. The data collected through interviews is effected by personal opinions and are not always accurate. To address this uncertainty, triangulation is used to validate the collected data. Interviews were combined with theory to strengthen the results. To ensure that a sufficient amount of information were collected, the process of data saturation was used. However, there are no guidelines for when to end the data collection in qualitative research, therefore some aspects or factors might have been excluded.

6.6 Limitations

An initial plan was to interview operators in the production plant to get different perspectives of the current production. However, communication delays and availability issues lead to that no interviews could be held with operators.

Initially, the thesis was planned to be carried out in collaboration with another thesis responsible for creating the virtual environment. The intention was to apply the developed workflow of this thesis to the virtual environment to make a demonstration. Due to difficulties with data and CAD models, a virtual scene could not be achieved in the required time frame of this thesis. This meant that no tests of the workflow could be made and no demonstration delivered.

7 Conclusion

The purpose of this thesis was to develop a workflow for virtual training that meets the requirement from production. This was accomplished by combining theory and research with the conditions of the production. The two research questions are answered below:

-Can virtual training meet the existing learning outcomes in the production environment?

The identified requirements from production can roughly be divided into two categories: knowledge-based aspects and craftsmanship. Craftsmanship involves requirements for assembly skills. These requirements regard how parts are physically assembled and how it feels for the operator, i.e. tactility. These are requirements linked to skill-based behaviour and tacit knowledge. Tacit knowledge is hard to present in an explicit form, i.e. it is hard to explain to an operator how to fasten a screw using a pneumatic tool. The procedure can be visualised to the operator, however, the operator needs to practice the procedure in the real world to improve his behaviour on the skill level. This implies that a virtual environment can not fully meet the existing learning outcomes from the production.

A virtual environment could, on the other hand, support learning regarding the second category of requirements. These requirements are connected to cognitive aspects of the assembly such as reading instructions, assemble in sequence and product knowledge. These aspects are regarded as articulated knowledge. Transferring articulated knowledge can be accomplished by codification, through the use of technology. Virtual training might decrease knowledge-based errors in production.

-What are the main functions to include in a workflow for virtual training?

The workflow presented in this thesis focus on functions within three phases of a training session. These phases are introduction, practice and evaluation, see figure 7.1.

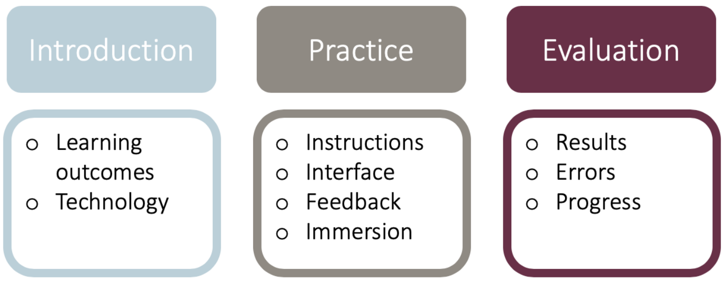


Figure 7.1: The main function identified during the three phases

The introduction part requires functions that explain the learning outcomes and the technology supposed to be used. The aim is to put the trainee at ease and arouse the interest of the trainee. This will set a foundation for the remainder of the training.

The practice phase need to decide on function regarding such as how instructions should be received, which interfaces should appear and what kind of feedback will be given to the trainee. It is in this phase that the trainee performs tasks and learn. Immersion is an important factor affecting the training outcome.

Finally, the evaluation of the trainee should present results from the training session. The results should be based on data collected during the practice phase, e.g. errors made. The training progress should be presented to keep the trainee engaged and motivated.

7.1 Future work

The workflow along with this thesis can act as a guide in the implementation of virtual training. However, the concept needs to be tested and validated in a real setting. It is necessary to involve the operators when designing the virtual training system in the future.

Further, it is essential to determine the role of virtual training in the organisation, i.e. as a compliment or a substitute. This decision affects how the system will be designed and implemented. It also affects to what extent the system will bring value to the organisation and improve the qualities of operator training.

Bibliography

[1] M.L. Dertouzos, R.K. Lester and R.M. Solow, *Problems of U.S. Industry*, *Science*, vol. 246, no. 4937, 1989.

[2] M. Yoshimura et al., “A rapid analysis method for production line design,” *International Journal of Production Research*, vol. 44, no. 6, pp. 1171–1192, Mar. 2006.

[3] L. Malmsköld, "Virtual training : preparatory training in automotive assembly," Ph.D dissertation, Department of Product and Production Development, Chalmers University of Technology, Gothenburg, Sweden, 2012.

[4] S. Hoedt, A. Claeys, H. Van Landeghem, and J. Cottyn, "The evaluation of an elementary virtual training system for manual assembly," *International Journal of Production Research*, vol. 55, no. 24, pp. 7496–7508, Sep. 2017.

[5] Y. Zhou, S. Ji, T. Xu and Z. Wang, “Promoting Knowledge Construction: A Model for Using Virtual Reality Interaction to Enhance Learning,” presented at *International Conference on Ambient Systems, Networks and Technologies*, 2018, pp. 239-246. [Online]. Available: `https://doi.org/10.1016/j.procs.2018.04.035`, Accessed on: Mars 15, 2019.

[6] S. Mujber, T. Szecsi, and M. S. J. Hashmi, "Virtual reality applications in manufacturing process simulation," *Journal of Materials Processing Technology*, vol. 155–156, pp. 1834–1838, Nov. 2004.

[7] K. Dampney, P. Busch, and D. Richards, "The Meaning of Tacit Knowledge," *Australasian Journal of Information Systems*, vol. 10, no. 1, Nov. 2002.

[8] S. Sudhindra, L. S. Ganesh, and K. Arshinder, "Knowledge transfer: an information theory perspective," *Knowledge Management Research & Practice*, vol. 15, no. 3, pp. 400–412, Aug. 2017.

[9] P. Ellström, "The many meanings of occupational competence and qualification," *Journal of European Industrial Training*, vol. 21, no. 6/7, pp. 266–273, Aug. 1997.

[10] T. Leung, F. Zulkernine and H. Isah, “The use of Virtual Reality In Enhancing

Interdisciplinary Research and Education," Queen's University, Canada, 2018. [Online]. Available: https://arxiv.org/abs/1809.08585, Accessed on: Feb 11, 2019.

[11] C.J. Chen, "Theoretical Bases for Using Virtual Reality in Education," *Themes in Science and technology Education*, vol.2, no.1-2, pp. 71-90, 2009. [Online]. Available: https://files.eric.ed.gov/fulltext/EJ1131320.pdf, Accessed on: Feb 12, 2019.

[12] J. Kretchmar, "Constructivism," in *Salem Press Encyclopedia* 2017, p. 7 [Online]. Available: http://proxy.lib.chalmers.se/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=ers&AN=89164134&site=eds-live&scope=site

[13] E. Wenger, *Communities of practice: learning, meaning, and identity.* Cambridge, England: Cambridge University Press, 1999.

[14] T.P. Wright, "Factors Affecting the Cost of Airplanes," presented at *Aircraft Operations Session*, 1936, pp. 122-128. [Online]. Available: http://www.uvm.edu/pdodds/research/papers/others/1936/wright1936a.pdf, Accessed on: 29 mars.

[15] M.F. Morris and M.I. Posner, *Human Performance*, Belmont, Calif, England: Brooks/Cole Publishing Company, 1967.

[16] J.R. Anderson, "Acquisition of Cognitive skill," *Psychological Review*, 1982, Vol. 89, no. 4, pp. 369-406.

[17] S. Mattsson, Å. Fast-Berglund, D. Li, and P. Thorvald, "Forming a cognitive automation strategy for Operator 4.0 in complex assembly," *Computers & Industrial Engineering*, Aug. 2018.

[18] T. B. Sheridan, "Human Supervisory Control," in *Handbook of Human Factors and Ergonomics*, John Wiley & Sons, Inc., 2012, pp. 990–1015.

[19] L. Malmsköld, R. Örtengren, and L. Svensson, "Improved Quality Output through Computer-Based Training: An Automotive Assembly Field Study," *Human Factors and Ergonomics in Manufacturing & Service Industries*, vol. 25, no. 3, pp. 304–318, Jan. 2014.

[20] S. Mattsson and Å. Fast-Berglund, "How to Support Intuition in Complex Assembly?," Procedia CIRP, vol. 50, pp. 624–628, 2016

[21] Ebbinghaus H. *Translation of memory: A contribution to experimental psychology.* (H.A.Ruger & C.E.Bussenius Trans.) New York: Teachers College, Columbia University, 1913 (Reprinted Bristol: Thoemmes Press, 1999).

[22] Icez, "A typical representation of forgetting curves.," 2007. [graph]. Avail-

able: https://en.wikipedia.org/wiki/Forgetting_curve#/media/File:ForgettingCurve.svg Accessed on: May 8, 2019

[23] Å. Fasth-Berglund, P. Thorvald, E. Billing, A. Palmquist, D. Romero & G. Weichhart, "Conceptualizing Embodied Automation to Increase Transfer of Tactic knowledge in the Learning Factory" presented at *International conference on Intelligent Systems*, 2018. [Online] Available: https://research.chalmers.se/publication/505114/file/505114_Fulltext.pdf, Accessed on: Mar 14, 2019.

[24] S. Fowler, *"Why motivating people doesn't work and what does"*, San Francisco, USA: Berret-Koehler Publishers, 2014.

[25] M. Osterloh and B.S. Frey, "Motivation, Knowledge Transfer, and Organizational Forms", 2000, pp.538-550. [Online]. Available: https://10.1287/orsc.11.5.538.15204, Accessed on: Apr 2, 2019.

[26] M. Pereira, M. Oliveira, A. Vieira, R. M. Lima, and L. Paes, "The gamification as a tool to increase employee skills through interactives work instructions training", *Procedia Computer Science*, vol. 138, pp. 630–637, 2018.

[27] G. Richter, D.R. Raban and S. Rafaeli, "Studying gamification: The effect of Rewards and Incentives on Motivation", in Gamification in Education and Business, Haifa, Israel: Springer International Publishing, 2015, pp. 21-46.

[28] P. Graupp and R.J. Wrona, *The TWI workbook: essential skills of supervisors*, New York, USA: Productivity Press, 2006.

[29] B. Flynn, S. Sakakibara, R. Schroeder, K. Bates and J. Flynn, "Empirical Research Methods in Operation Management," *Journal of Operation Management*, vol. 9, no. 2, pp. 250-284, Apr, 1990. [Online]. Available: https://doi.org/10.1016/0272-6963(90)90098-X, Accessed on: Apr 24, 2019.

[30] J.W. Creswell, *Research Design: Qualitative, Quantitative and Mixed Methods Approaches*, Thousand Oaks, USA: SAGE Publications, 2014.

[31] J. Saldana, *Fundamentals of Qualitative Research.* New York, USA: Oxford University Press, 2011.

[32] M. Hennink, I. Hutter and A. Bailey, *Qualitative Research Methods*, Los Angeles, USA: SAGE Publications, 2011.

[33] R.K. Yin, *Case Study Research: Design and Methods*, London, England: SAGE Publications, 2014.

[34] G. Guest, K.M. MacQueen and E.E. Namey, *Applied thematic analysis*, Thousand Oaks, USA: SAGE Publications, 2012.

[35] M. Denscombe, *The good research guide: for small scale research projects*, 5th ed., Maidenhead, England: Open University Press, 2014

[36] J. M. Morse, “The Significance of Saturation,” Qualitative Health Research, vol. 5, no. 2, pp. 147–149, May 1995

[37] I. Dey, "Grounded Theory" in *Qualitative Research Practice*, C. Seale, G. Gobo, J. Gubrium and D. Silverman, Ed. London, England: SAGE Publications Ltd, 2004, ch. 5, pp. 81-94. [Online]. Available: `https://dx.doi.org/10.4135/9781848608191`, Accessed on: Apr 21, 2019

[38] L. M. Given, "Triangulation" in *The Sage encyclopedia of qualitative research methods*. vol. 2, Los Angeles, USA; London, England: SAGE, 2008, pp. 893-894. [Online]. Available: `http://dx.doi.org/10.4135/9781412963909` , Accessed on: Apr 22, 2019

[39] You, F., Y. Tan, J. Feng, L. Li, J. Lin, and X. Liu. “Research on Virtual Training System in Aerospace Based on Interactive Environment” Presented at *International Conference on Technologies for E-Learning and Digital Entertainment*, 2016, pp. 50–62. Cham: Springer

[40] A. Guisinger and B. Ghorashi, (2004) "Agile manufacturing practices in the specialty chemical industry: An overview of the trends and results of a specific case study", *International Journal of Operations & Production Management*, Vol. 24 Issue: 6, pp.625-635, [Online]. Available: `https://doi.org/10.1108/01443570410538140`, Accessed on: Apr 22, 2019.

[41] D. Gorecky, M. Khamis and K. Mura, “Introduction and establishment of virtual training in the factory of the future”, *International Journal of Computer Integrated Manufacturing*, vol.30, no. 1, pp. 182-190, Jul. 2015. [Online]. Available: `https://doi.org/10.1080/0951192X.2015.1067918` , Accessed on: Feb 11, 2019.

[42] A. Langley et. Al, “Establishing the Usability of a Virtual Training System for Assembly Operations within the Automotive Industry”, *Human Factors & Ergonomics in Manufacturing & Service Industries*, vol. 26, no. 6, pp. 667-679, Jul, 2016. [Online]. Available: `http://dx.doi.org/10.1002/hfm.20406`, Accessed on: Feb 11, 2019.

[43] Vélaz, Y., J. R. Arce, T. Gutiérrez, A. Lozano-Rodero, and A. Suescun. 2014. “The Influence of Interaction Technology on the Learning of Assembly Tasks Using Virtual Reality.” *Journal of Computing and Information Science in Engineering*, vol.14, no.4, 2014.

[44] S. Hoedt, A. Claeys, H. Van Landeghem and J. Cottyn, ”Evaluation Framework for Virtual Training within Mixed-Model Manual Assembly”, in *IFAC-PapersOnLine*, 2016, pp. 261-266.

[45] F. Loch, F. Quint and I. Brishtel, “Comparing Video and Augmented Reality Assistance in Manual Assembly,” presented at: *2016 12th International Conference on Intelligent Environments (IE)*, 2016.[Online]. Available: `https://doi.org/10.1109/IE.2016.31`, Accessed on: March 20, 2019.

[46] C. Fowler and J. Mayes, "Learning relationships from theory to design", ALT-J, vol. 7, no. 3, pp. 6-16, 1999. [Online]. Available: `https://doi.org/10.1080/0968776990070302`, Accessed on: Feb 16, 2019.

[47] C. Fowler, “Virtual reality and learning: Where is the pedagogy?”, in *British Journal of Educational Technology*, vol.46, no.2, pp. 412-422, 2015. [Online]. Available: `https://doi.org/10.1111/bjet.12135`, Accessed on: Feb 16, 2019.

[48] A. Syberfeldt, O. Danielsson, M. Holm and L. Wang, “Dynamic operator instructions based on augmented reality and rule-based expert systems”, in *48th CIRP Conference on MANUFACTURING SYSTEMS*, 2015, pp. 346-351. [Online]. Available: `https://doi.org/10.1016/j.procir.2015.12.113`, Accessed on: Feb 11, 2019.

[49] J. Campos, "Managing the information systems in the industrial domain", *Cogent Business & Management*, vol. 3, no. 1, May 2016. [Online]. Available: `http://dx.doi.org/10.1080/23311975.2016.1180967`, Accessed on: Feb 11, 2019.

[50] Y. Zhang, T. Fernando, H. Xiao and R.L. Travis, "Evaluation of auditory and visual feedback on task performance in a virtual assembly environment", Presented at *Teleoperators and Virtual Environments*, vol. 15, no. 6, pp. 613-626, 2006.

[51] R. Etemadpour, E. Monson and L. Linsen, "The effect of stereoscopic immersive environments on projection-based multi-dimensional data visualization", in *IV*, pp. 389-397, 2013.

[52] Volvo Trucks, "General Media Gallery", 2019 [Online]. Available: `https://images.volvotrucks.com/categories`, Accessed on: May 09, 2019

[53] J. J. Laviola, "A discussion of Cybersickness in Virtual Environments," *SIGCHI Bulletin*, vol. 32, no. 1, pp. 47-56, Jan, 2000. [Online]. Available: `https://doi.org/10.1145%2F333329.333344`, Accessed on: May 08, 2019